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THESIS

DESIGN, CONSTRUCTION AND TESTING OF A
PROTOTYPE FIN-LINE MAGIC-TEE AND FIN-LINE
MONOPULSE SYSTEM SUITABLE FOR
MILLIMETER-WAVE APPLICATIONS

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Design, Construction and Testing of a Prototype Fin-Line
Magic-Tee and Fin-Line Monopulse System Suitable for
Millimeter-Wave Applications

by

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ABSTRACT

This thesis describes a fin-line 180 degree hybrid (magic-tee) that is suitable for use in monopulse radar antennas at microwave and millimeter-wave frequencies.

The three-dimensional junction of a waveguide magic-tee is replaced with fin-line slots, coupled fin-line slots and microstrip lines mounted in a waveguide fixture. The planar geometry on the substrate provides significant reduction in size and eliminates the waveguide ratrace that is associated with conventional hybrids. Ports one and two are flared into fin-line horns to produce a fin-line monopulse system. Suggestions for further development of the fin-line magic-tee and monopulse system are presented.

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I. INTRODUCTION

A. BACKGROUND

This thesis describes the successful design, construction and testing of both a fin-line magic-tee and monopulse system. Each of these units is probably the first devices of their type constructed.

There are two main categories of magic-tees; the conventional waveguide hybrids, and the new planar devices [Ref. 1: pp. 259-261]. The fin-line magic-tee, developed in this thesis, is in the latter category.

The 180 degree hybrid, or magic-tee, is a passive four port device. It is an essential part of many microwave components, including balanced mixers, single-sideband modulators, frequency multiplexers, linear phase shifters, constant impedance filters, IFM (instantaneous frequency measurement) receivers, interferometers, duplexers and monopulse radar comparators [Ref. 1: pp. 259-261 and Ref. 2: pp. 16-18]. While many of these applications use only one hybrid, monopulse antennas contain a complex network of magic-tee comparators.

Monopulse comparator networks require exact symmetry between numerous sections of transmission lines for proper operation. Unbalanced phase shifts of only a few degrees,

due to uneven lengths of transmission line, destroy the target tracking capability of the system [Ref. 3].

Waveguide comparator networks, with bolted together flanges or soldered connections, have difficulty achieving these exacting lengths at millimeter-wave frequencies. This effect limits most of the current monopulse radars to frequencies well below the millimeter-wave band [Ref. 3].

Another limitation of the waveguide hybrid occurs because three of the four ports are on mutually orthogonal axes. It is this three dimensional shape that produces the complex waveguide ratrace and intricate network of soldered flanges in conventional monopulse antennas [Ref. 2: pp. 10-17 and Ref. 3].

Unlike the waveguide magic-tee, all four ports of the new hybrids are in the same plane. This two dimensional geometry greatly simplifies the interconnections between the numerous comparators in a monopulse antenna system. With the planar magic-tees, the confusing and costly maze of waveguide discussed above can be eliminated.

In addition to the fin-line magic-tee designed in this thesis, two other types of planar magic-tees have recently been developed [Ref. 3 and Ref. 4: pp. 523-528]. However, only one of these new hybrids is designed as a monopulse comparator [Ref. 3].

The fin-line magic-tee developed in this thesis and the new fin-line horn antenna developed in a parallel thesis [Ref. 5] are designed to be computer manufactured as a

single unit. This combination of fin-line horns and fin-line magic-tees constructed in an integrated unit, is hereafter called a fin-line monopulse system, or a fin-line monopulse comparator. Fin-line monopulse systems, operating at millimeter-wave frequencies, can potentially be mass produced for a few hundred dollars each.

B. RELATED WORK

1. Slotline Magic-Tee

Mr. M. Aikawa and Mr. H. Ogawa [Ref. 4] pp. 523-528] introduced a slotline magic-tee. The fin-line magic-tee developed in this thesis (Fig. 1) is similar to two of these slotline hybrids placed back to back in a waveguide fixture.

There are five major differences between the fin-line magic-tee developed in this thesis and the slotline magic-tee described in Reference 4.

First, the fin-line hybrid is essentially two slotline hybrids in parallel with each other. This configuration significantly changes the impedance characteristics of the circuit.

Second, the waveguide fixture that surrounds the fin-line device, changes all of the impedances as a function of frequency.

Third, the unique microstrip to coaxial transition used in the fin-line device does not have a counterpart in the slotline magic-tee. The purpose of this transition is to

maintain a fairly wide bandwidth at the point where the microstrip passes through the waveguide wall.

Fourth, the slotline hybrid uses a tapered section to transition from the main loop to the coupled slot area. In the corresponding portion of the fin-line magic-tee, each section of microstrip maintains a constant width up to the point where the two sections join.

Finally, all of the bends in the slots of the fin-line magic-tee are computer designed to keep incidental reflections as low as possible.

2. Planar Waveguide Comparators

The system described by Syrigos, Crossland and Van Wyck [Ref. 3] is not related to this thesis at all. However, it does meet part of the objectives of this work by utilizing a totally different design and manufacturing concept.

3. Fin-Line Horn Antenna

The fin-line horn antenna was perfected by LCDR Muntaz-ul-Haq [Ref. 5]. Haq discovered that a substantial amount of the electric field can be launched between the parallel fins. This undesirable effect can be successfully controlled by making the horn fins half of a wavelength wide and shorting the exposed edges together with copper tape. This short reflects another short across the edges of the fin-line slots. The reflected short seals the gap between the fins and keeps the electric field in the slots.

The parallel slots leading to ports one and two (Fig. 1) are separated by a quarter wavelength. Each slot appears as an open to the other slot, reflecting back a short a quarter of a wavelength away. The reflected short seals off the two slots, thereby preventing inadvertent coupling. This concept is a direct result of the applied research performed by Haq [Ref. 5].

C. PURPOSE

The first objective of this work is to design, build and successfully test a fin-line magic-tee at 10-GHZ. This includes the design and construction of a suitable fixture to hold the magic-tee. The final magic-tee is to be integrated with two fin-line horn antennas [Ref. 5], to form a two dimensional fin-line monopulse system (only one difference channel).

The second objective is to produce reasonable sum and difference antenna patterns from the combined one piece unit. This integrated unit is intended to be the prototype of a millimeter-wave fin-line monopulse system that has both azimuth and elevation difference channels.

The third and most important objective is to computerize the design procedure. This will insure the ability to accurately and quickly reproduce these devices at a future date.

The final objective of this research is to recommend possible improvements for the fin-line magic-tee and

fin-line monopulse system. Specific recommendations for expanding the fin-line monopulse system into a three channel (sum channel, azimuth channel and elevation channel) monopulse system are required.

II. THEORETICAL PRINCIPLES

The design of the fin-line magic-tee and monopulse system is based on established microwave principles. These theoretical concepts are discussed in this chapter.

A. WAVEGUIDE MAGIC-TEE

The theoretical properties of a waveguide 180 degree hybrid are illustrated in Figures 2 and 3. An input at any one of the four ports is equally divided with half of the power coupling into two orthogonal ports. In phase signals at ports one and two combine in the H-plane arm and cancel in the E-plane arm. Out of phase inputs at ports one and two produce the opposite results. There is complete isolation between ports one and two and between ports three and four. The reverse of these conditions is also true. The 180 degree phase shift depicted in Figure 3 can occur in either S₂₃ and S₃₂ as shown, or in S₁₃ and S₃₁ [Ref. 6: pp. 190-191].

B. MONOPULSE ANTENNAS

The typical monopulse radar antenna contains four identical antenna elements, which are interconnected with three or more magic-tees. The signals to and from the four elements are added and subtracted in various combinations to produce three system ports.

All four of the antennas are summed together in phase to produce the sum channel. This signal is connected to the radar via a T/R (Transmit/Receive) Device.

The two difference channels are the radar's source of target tracking information. The elevation port produces the difference between the upper and lower antennas while the azimuth port produces the difference between the left and right antennas. If a monopulse antenna system is pointing exactly at a target, there will be a strong signal in the sum channel and absolutely no signal in either the elevation or azimuth channels. The null in the difference channels is the result of shifting two identical signals 180 degrees from each other and then adding them together. The phase shift and addition occur within the magic-tees.

The radar return from a target that is slightly left of the monopulse antenna's extended center line reaches the left elements of the antenna before it reaches the right elements. This produces a slight phase shift due to the difference in arrival times at the left and right elements. Complete cancellation does not occur in the difference channel with this configuration. The resulting difference signal increases in amplitude and shifts in phase as the target gets farther away from the antennas extended center line. There is also a 180 degree phase shift in the difference channel as a target crosses the antenna's extended center line [Ref. 7: pp. 10-29].

Since the null in the difference port can only occur with exact target/antenna alignment, it signifies the exact

center of both the sum and difference antenna patterns. Therefore, a target that produces a strong return in the sum channel and no return in one of the difference channels is on a plane that bisects the two antennas which develop the difference signal. When this information is combined with range data, the target's location is limited to an arc on the plane that bisects the two halves of the antenna. The point where the elevation and azimuth arcs cross is directly in front of the antenna. The line between the monopulse antenna and this point is commonly referred to as the boresight of the antenna.

If the outputs of the difference channels are monitored while a target is within the main beam of the sum pattern, the target can be classified as exactly centered, a little left or right, a little high or low, or any combination of these directions.

Skolnik [Ref. 7: pp.10-28] defines an amplitude comparison monopulse system as one that compares the amplitude of the difference channel with the amplitude of the sum channel. This information is used to determine how far a target is away from the antenna's boresight. The phase (+/- only) of the difference signal is used to determine which side of boresight the target is on.

This technique was initially called simultaneous lobing since all of the radiation lobes are sampled during each and every pulse. The ability to obtain a complete tracking

solution in only one pulse led to the current designation of monopulse [Ref. 7: p. 10].

Earlier tracking radars such as conical scanning and lobe switching systems required numerous radar returns to obtain the same information. The accuracy of these systems is often degraded by pulse to pulse amplitude variations. Monopulse radars, which are free of this distortion, have achieved tracking accuracies of 0.003 degrees [Ref. 7: P. 10].

Two popular forms of amplitude comparison monopulse antennas are illustrated in Figures 4 and 5.

C. THEORETICAL ANTENNA PATTERNS

The far field effect an antenna has on the environment is a direct result of the current distribution across the face of the antenna and can be represented mathematically with a specialized Fourier Transform [Ref. 8: pp. 345-369 and Ref. 9: pp. 170-195]. This technique is used to develop computer simulations of actual sum and difference patterns. The simulated patterns are used to illustrate the theoretical properties of a monopulse system.

The first step in predicting a theoretical monopulse antenna pattern is to obtain the element pattern by taking the Fourier Transform of the current distribution across the face of one of the elements. The second step is to determine the array or group pattern by taking the Fourier Transform of the entire array, assuming that each antenna element is a

delta function. The final step is to multiply the element pattern with the array pattern.

An actual E-plane antenna pattern from one of the fin-line horns of Reference 5 is closely simulated by adding 20% of a $\sin(x)/x$ pattern, to 80% of $\sin(x)/x$ squared pattern (Fig. 6). This simulation is used as the predicted element pattern.

The group pattern is obtained by taking the trivial transformation of two delta functions. This results in a cosine function for the sum pattern and a sine function for the difference pattern. These theoretical group patterns with an element spacing of one wavelength are illustrated in Figures 7 and 8.

The multiplication of the simulated element and group pattern is done in a short Basic program on an HP-9845B Computer. The theoretical sum and difference patterns computed in this program are shown in Figures 9 and 10, respectively.

D. SLOTLINE CHARACTERISTICS

Slotline consists of a narrow slot in a thin plating of metal foil adhered to one side of a thin layer of dielectric. The other side of the supporting substrate is void of metal. The electric field is guided between the edges of the slot. The impedance of the slot is directly proportional to the width of the slot. A detailed analysis

of slotline properties is presented by Gupta, Garg and Bahl [Ref. 10: pp. 195-228].

E. FIN-LINE CHARACTERISTICS

The bilateral fin-line illustrated in Figure 11 has one straight slot on each side of the dielectric. The fin-line magic-tee uses a similar, but more complex configuration which has two slots on each side of the dielectric. The slots in the magic-tee have a mixture of straight, angled and curved sections which join together in a 180 degree bend (Fig. 1). Both of these designs are formed by suspending dual sided slotline in the E-plane of a section of waveguide. As such, they are essentially shielded slotline. As is the case with slotline, the impedance of fin-line is directly proportional to the width of the slot. The detailed properties of fin-line are discussed by Sharma and Hoefer [Ref. 11: pp. 350-355] and Meier [Ref. 12: pp. 1209-1215].

F. EVEN AND ODD MODES IN COUPLED SLOTS

Two identical and parallel slots in either slotline or fin-line are considered coupled if the impedance and electrical length of one slot is effected by the proximity of the other slot. Coupled slots are the key to the operation of both the slotline magic-tee discussed in Reference 4 and the fin-line magic-tee developed in this thesis.

Knorr and Kuchler [Ref. 13: PP. 541-547] define two dominate modes in coupled slots: even or odd. The even mode exists when the electric fields within the two slots are in

phase with each other; whereas, the odd mode exists when the two electric fields are out of phase with each other.

In the even mode, the magnetic fields which surround each slot couple together smoothly to form one continuous magnetic field. In this configuration, the fields aid each other and produce a coupled impedance which is lower than the uncoupled impedance [Ref. 10: p. 352].

As the slots are brought closer together, the coupling increases. This effect causes the even mode impedance to decrease. In the limit when the separation between the slots vanishes, each slot has half of the impedance of the new slot which is twice as wide as each of the original slots. At the other limit when the distance between the slots is infinite, each slot retains its uncoupled characteristics [Ref. 10: p. 355].

In the odd mode, the magnetic fields oppose each other and do not join together smoothly. Because of this opposition, the odd mode impedance is higher than the uncoupled impedance. As the two slots are brought closer together, the opposition between the two magnetic fields and the odd mode impedance increase [Ref. 10: p. 352].

In the limit, when the separation between the slots vanishes, there is complete opposition between two equal and opposite magnetic fields. In this condition, the odd mode impedance of each slot is exactly twice the uncoupled impedance of one of the original slots [Ref. 10: p. 355].

The electrical length of coupled slots is longer than the uncoupled length in the even mode and shorter than the uncoupled length in the odd mode. These differences become larger as the two slots are brought closer together [Ref. 13: pp. 543-545].

G. MICROSTRIP CHARACTERISTICS

The microstrip that is used in this thesis is composed of a narrow center conductor with dielectric material and a ground plane on both sides. If the two ground planes are bent around the center conductor until they touch, it will resemble coaxial cable. This dual sided microstrip, defined as "triplane line" by Reference 6, and coaxial cable both operate in the TEM mode [Ref. 6: pp. 38-61].

H. MICROSTRIP TO SLOTLINE TRANSITIONS

A simple and effective transition from slotline to microstrip is presented by Knorr [Ref. 14: pp. 548-553]. With this technique an open length of microstrip on one side of a section of dielectric overlaps a shorted slot on the other side of the same substrate at a 90 degree angle. The portion of the slot that extends past the microstrip, and the portion of the microstrip that extends past the slot are exactly one quarter of a wavelength long. At the junction there is a reflected short in the microstrip and a reflected open in the slot. This procedure is used in both the fin-line magic-tee and the fin-line monopulse system.

With thin substrates and high dielectric constants, the power transfer through this type of transition is close to 1:1 [Ref. 14: pp. 548-553]. The fin-line magic-tee and the fin-line monopulse system developed in this thesis are made from Epsilam-10 which is 0.025 inches thick and has a dielectric constant of 10.2. The return loss of these transitions is minimal.

I. IMPEDANCE MATCHING

A quarter wave length impedance matching technique is used in the fin-line magic-tee. This procedure joins two slots of unequal impedances together with a quarter wave length matching section. The impedance of the center matching slot is equal to the square root of the product of the two original impedances.

If the original impedances are called Z_a and Z_b , and the matching section is called Z_o , the relationship becomes Z_o equals the square root of Z_a times Z_b .

This relationship is easily visualized on a normalized Smith Chart. Z_o is the center of the chart and Z_a is somewhere to the left of center on the real line. Traveling a quarter of a wave length through the matching section of impedance Z_o is represented on the Smith Chart by a half circle of radius Z_a , which is centered at Z_o . The end of this half circle will be on the real line to the right of Z_o . If the algebraic relationship discussed above is maintained, this point will be Z_b .

The proof of this relationship is based on the fact that all of the points on the left half of the real line of a Smith Chart are the reciprocals of the equal distance points on the right side of the real line. Therefore, as long as Z_a and Z_b are on different sides of the real line and equal distance from the center, their product is unity. Since the center of a normalized Smith Chart is Z_0 which has a value of 1.0, the algebraic relationship discussed above produces a perfect impedance match.

III. FIN-LINE MAGIC-TEE

The fin-line magic-tee is designed to mate with two fin-line horns from Reference 5 to form a fin-line monopulse antenna. To provide a smooth transition between the magic-tee and the horns, a bilateral fin-line magic-tee enclosed in a waveguide fixture is developed. The dielectric is Epsilam-10 which has a thickness of 0.025 inches and a dielectric constant of 10.2.

A. ENGINEERING APPROXIMATIONS

Four major engineering approximations are used in the design of the magic-tee. These approximations greatly facilitate the design process without introducing significant inaccuracies.

1. Parallel Circuit Approximation

An extensive search of the current literature failed to turn up design data for a complex fin-line structure with coupled bilateral fin-line slots at a dielectric constant of 10.2. Therefore, the bilateral fin-line is modeled as two identical unilateral (one sided) circuits in parallel.

Sharma and Hoefer [Ref. 11: pp. 350-355] compared the properties of bilateral fin-line and unilateral fin-line with dielectric constants of 2.22 and 3.0. An 80 ohm, 0.050 inch thick section of bilateral fin-line has 57% of the impedance of a similar section of 0.025 inch thick

unilateral fin-line. Changing the dielectric constant to 3.0 drops the ratio to 55%. The same comparison with 0.025 inch thick, 200 ohm unilateral fin-line produces an 84% ratio at a dielectric constant of 2.22 and a 73% ratio with the 3.0 dielectric constant.

At a dielectric constant of 10.2, the low impedance slots should closely fit the parallel circuit model. There may be a slight error for the largest unilateral impedance in the fin-line magic-tee, which is 200 ohms. However, this error should be minimal.

2. Fixtures Effect on Impedance

Kuchler [Ref. 15: p. 103] compared the impedances of shielded and unshielded slotline with a dielectric constant of 20. Between 10- and 12-GHZ for a dielectric thickness of 0.050 inches, the shielded and unshielded impedances are almost identical. The impedance of the shielded slot is constant to 6-GHZ. The impedance of the unshielded slot is approximately 10% lower at 6-GHz than it is at 12-GHZ.

The quarter wavelength impedance matching technique discussed in Chapter Two is the only type of impedance matching used in the fin-line magic-tee. This technique's simple algebraic relationship will factor out any uniform change in impedance. Therefore, the fixture should not effect the impedance matching between the slots. There may be a slight mismatch between the slots and the microstrip

leads, but this mismatch should be minimal [Ref. 15: p. 103].

Based on the first two engineering approximations, all of the impedances in the fin-line magic-tee are calculated as slotline impedances with a dielectric thickness of 0.025 inches. All of the slotline impedances are exactly twice the desired bilateral fin-line impedances.

3. Length of the Coupled Slots

The electrical length of coupled slots is different in the even and odd modes [Ref. 13: pp. 541-547]. The actual length of the coupled slots in the slotline magic-tee [Ref. 4: p. 527] is the average of the even and odd mode quarter wavelengths.

Knorr and Kuchler [Ref. 13: pp. 544, 545] graphed the even and odd mode wavelengths for dielectric constants of 11.0 and 16.0. On both of these graphs, the average of the even and odd mode wavelengths is 97% of the uncoupled electrical length. This percentage holds for a very wide range of slot separation distances, including the separation that is used in the fin-line magic-tee.

The length of the coupled slots in the fin-line magic-tee is designed to be 97% of the value of a similar section of uncoupled slotline.

4. Dielectric Termination within the Fixture

Due to the complex geometry of the fin-line magic-tee (Fig. 1) the conventional configuration for the

bilateral fin-line shown in Figure 11 is not feasible. The fin-line magic-tee uses a 0.02 inch groove in the fixture wall to support the dielectric. This groove shorts and electrically seals the edges of the fins.

B. EQUIVALENT CIRCUIT

The fin-line magic-tee is similar to two slotline magic-tees placed back to back and mounted in a waveguide fixture [Ref. 4: pp. 523-527]. The equivalent circuit for the fin-line magic-tee is similar to the circuit shown for the slotline magic-tee on page 525 of Reference 4. The fin-line device is represented by two of these circuits connected in parallel. The fin-line version is surrounded by a shield.

1. Theoretical Operation

An actual 1:1 scale drawing of the fin-line magic-tee is illustrated in Figure 1. With the exception of port three, the entire magic-tee is symmetric about an axis that extends through the center of the port four microstrip line. The theoretical operation of the fin-line magic-tee is identical to the operation of the slotline magic-tee [Ref. 4: pp. 523-527].

The microstrip leads from all four ports use the microstrip to slot transition technique discussed in Chapter Two. The short in the loop caused by the port four microstrip effectively isolates ports one and two. Ports three and four are isolated from each other by the $3/4$ of a

wavelength distance between the short in the loop and the short caused by the port three microstrip.

Two signals that enter the coupled slots in the even mode will couple into port three. There will be a slight phase shift between the two signals in the port three microstrip line. This error is inherent in the design of the device and can only be minimized by keeping the slot separation as small as possible. The even mode signals cancel at port four due to the loop geometry.

Two signals that enter the coupled slots in the odd mode will be out of phase at port three but will couple in phase at port four. The theoretical operation of the fin-line magic-tee is identical to the scattering matrix for the waveguide magic-tee (Fig. 3).

2. Theoretical Impedance Matching

The unilateral impedances in the fin-line magic-tee are 200 ohms in the loop, 100 ohms in the slots that connect to ports one and two, and 70.7 ohms and 141.4 ohms for the even and odd mode in the coupled slots, respectively. These reduce to bilateral impedances of 100 ohms, 50 ohms, 35.4 ohms and 70.7 ohms, respectively. These bilateral values are identical to the impedances listed for the "case three" slotline magic-tee [Ref. 4: p. 527]. A detailed discussion of the theoretical impedance matching in the slotline magic-tee is presented by Aikawa and Ogawa [Ref. 4: pp. 524-527].

There are four basic relationships that require impedance matching within the magic-tee. The paths from port three to ports one and two and from port four to ports one and two must be matched in the even and odd modes. In all of these cases the coupled slots act as a quarter wavelength matching section. The impedance matching problem either reduces to three series impedances of 100, 70.7 and 50 ohms, or 50, 35.4 and 25 ohms. In all cases, the impedance of the coupled slots is the square root of the other two impedances.

C. SLOT IMPEDANCE AND ELECTRICAL LENGTH

1. Uncoupled Slots

Cohn [Ref. 16; p. 1092] graphed slotline impedance and effective wavelength for dielectric constants of 9.6 and 11.0. The data points on Figure 12 and 13 are extrapolated from Cohn's graphs for a dielectric constant of 10, a dielectric thickness of 0.025 inches and a frequency of 10-GHZ. All of the slot widths and electrical lengths in the fin-line magic-tee are derived from this information.

2. Coupled Slots

As discussed in Chapter Two, the odd mode impedance of coupled slots with no separation is equal to twice their uncoupled impedance. Their even mode impedance with no separation is one half of the uncoupled impedance of the new larger slot [Ref. 10; p. 355].

Knorr and Kuchler [Ref. 13: pp. 544, 545] graphed the even and odd mode impedances of coupled slots for dielectric constants of 11 and 16. A normalized version of this information is plotted in Figure 14 for a dielectric thickness of 0.025 inches and a frequency of 10-GHZ.

The normalization in Figure 14 is non-standard. The normalizing impedance is the slot impedance for S/D (slot separation/dielectric thickness) approaching infinity. The minimum value of zero is equivalent to the even mode impedance with no slot separation. This correlates to half of the uncoupled impedance of a slot that is twice as wide as the original slots. The center value of 1.0 represents an infinite slot separation. This is equivalent to the uncoupled impedance of each slot. The maximum value of 2.0 is the same as the odd mode impedances with zero slot separation. This corresponds to twice the impedance of the uncoupled slots.

The width of the coupled slots and the separation between the coupled slots are determined by trial and error. During this process impedances from Figure 12 are assigned to the normalized values of zero, 1.0 and 2.0 shown in Figure 14. The curve for a dielectric constant of 11.0 is used in this procedure. Based on the comparison between the curves for dielectric constants of 11.0 and 16.0 (Fig. 14), little error will be induced by this approximation.

First, an arbitrary value for the uncoupled impedance is chosen. To illustrate this procedure, an

initial value of 100 ohms is used for the uncoupled impedance. The normalized impedance of 1.0 (Fig. 14) is assigned this value (100 ohms). The normalized impedance value of 2.0 (Fig. 14) is set equal to twice this value (200 ohms).

Second, the slot width (0.4340 millimeters) for this arbitrary impedance (100 ohms) is obtained from the 0.635 millimeter curve in Figure 12. The impedance (132.2 ohms) of a slot twice this wide (0.8680 millimeters) is also calculated from Figure 12. The normalized impedance of zero (Fig. 14) is set equal to half of this value (66.15 ohms).

Third, the impedances in Figure 14 are now scaled for a dielectric constant of 10. The lower portion of the graph is linear from 66.15 ohms (normalized value of zero) to 100.0 ohms (normalized value of 1.0). The upper portion is linear from 100.0 ohms (normalized value of 1.0) to 200.0 ohms (normalized value of 2.0). On this scaled version of Figure 14, an S/D is picked that corresponds to an odd mode impedance of 141.4 ohms. If the correct value is selected for the uncoupled impedance (step one), the even mode impedance will be the required 70.7 ohms. In this example, the normalized odd mode impedance of 1.414 corresponds to an S/D of 0.5613 and a normalized even mode impedance of 0.4174 (Fig. 14). This equates to an actual even mode impedance of 80.28 ohms.

Fourth, this process is repeated until the scaled version of Figure 14 produces an odd mode impedance of 141.4 ohms and an even mode impedance of 70.7 ohms for the same S/D. There is only one uncoupled impedance (Fig. 12) and one S/D (Fig. 14) that produce this relationship for each specific dielectric constant.

For Epsilam-10, the uncoupled impedance that matches this criteria is 92.3 ohms. The actual slot width is 0.0134 inches (0.3401 millimeters). The correct S/D is 0.4187. The normalized impedances are 0.3383 for the even mode and 1.5320 for the odd mode. The actual distance between the slots is 0.0105 inches (0.2659 millimeters).

The last step is to determine the slot wavelength from the 0.635 millimeter curve in Figure 13. The proper value for an S/D of 0.4187 is 0.5132 times the free space wavelength (Fig. 13). As discussed in the engineering approximations section, 97% of a quarter wavelength is used for the length of the coupled slots. This value is 0.1470 inches (3.7335 millimeters).

All of these calculations are done on two foot by three foot computer generated replicas of Figures 12, 13 and 14. The values are picked off of these large charts with calipers.

D. FIXTURE DESIGN AND ASSEMBLY

The fixture for the magic-tee is used to hold the fin-line monopulse system. A 1:1 scale drawing of the original version of the fixture is illustrated in Figure 15.

The fixture is constructed from WR-90 copper waveguide. The two mirror image halves have 0.020 inch deep and 0.025 inch wide grooves in all three of the edges of the joining seam.

The two sections of dielectric are placed into these grooves. Then the microstrip launchers for ports three and four are set into place and soldered to the microstrip leads. Only one of the mirror image sections of dielectric is etched with microstrip. The other piece is void of metal on the inside.

After the two launchers are soldered in place, the fixture is bolted together. At this point, the launchers for ports one and two are attached.

The original design used OSM 2070-5029-02 launchers for all four ports. With this design, the launchers are held in place by the fixture when it is bolted together. The launcher is not screwed into the fixture. This arrangement does not provide a satisfactory electrical contact between the fixture and the launchers.

The fixture was modified to accept OSM 2052-1658-02 two hole flange mount jacks. The flange mounted jacks are attached to the fixture with small screws. This configuration provides good electrical continuity between the fixture and the connector.

E. FIN-LINE MAGIC-TEE DESIGN

1. Slotted Side

The length of the loop is $3/4$ of a wavelength from the port three microstrip to the port four microstrip. The

width of the loop slot and the separation between the two halves of the loop are operator adjustable variables. The computer program (Appendix A) calculates the length of the portions of the loop, and adjusts the length of the straight section in the loop to keep the overall length equal to $3/4$ of a wavelength.

The top and bottom lengths of the coupled slots are vastly different. The calculated quarter wave length is equal to the average of these two lengths.

All of the bends in the slots are constructed in the same manner. A line extending through a bend from corner to corner will bisect the angle of the bend. In this manner, the corners in a 90 degree bend are offset from each other by 45 degrees. In a 45 degree bend, the offset angle is 22.5 degrees. This arrangement insures that the slotwidth in the bend is at least as wide as the slots that lead into the bend.

All of these relationships are calculated by the computer program which draws the magic-tee.

The slots that lead to ports one and two are spaced wide apart for the first two magic-tees and closely together for the third magic-tee and for the fin-line monopulse system. In magic-tees one and two, the slots are 0.01 inches from the edge of the fixture.

In the third magic-tee and the fin-line monopulse system, the distance from the slots to the fixture groove is

twice as large as the distance between the slots. At 11.4-GHZ these distances are one half and one quarter of a wavelength, respectively. The half wavelength short and the quarter wave length open effectively seal the edges of the fins within the slot.

2. Microstrip Side

The widths of the microstrip lines are taken from Saad's microstrip impedance graph [Ref. 17: p. 117].

The transitions from microstrip to coaxial cable are unique. The metal foil on the slotline side of the dielectric acts as the ground plane for the microstrip. Near the connectors, this ground plane is parted in a "V" shape (Fig. 1). At the same time the width of the microstrip is flared at a lesser angle. The flare in the microstrip is adjusted to maintain a 50 ohm impedance at every point in the line.

The notch in the ground plane is flared at a 45 degree angle in each direction. The total angle of the notch is 90 degrees. The maximum width of the notch occurs at the inside edge of the fixture. At this point, the width of the notch exactly matches the diameter of the hole in the fixture wall, which exactly matches the outside diameter of the dielectric within the flanged launcher.

The magic-tee dielectric extends through the hole in the fixture and touches the launcher's dielectric. With this alignment, the inside wall of the shield on the coaxial

cable transitions smoothly through the launcher to the edge of the ground plane notch.

This microstrip to coaxial cable transition minimizes physical discontinuities that could cause inductive or capacitive reactances [Ref. 18: p. 95]. This lack of reactance maximizes the bandwidth through the fixture wall.

F. MANUFACTURING PROCESS

A simple form of computer aided design is adapted for this project. A BASIC Computer Program, written on an HP 9845B computer (with an HP Graphics ROM), controls an HP 9872C Plotter. The plotter draws the outline of the magic-tee four times the actual size (4:1 scale). The outline is filled in by hand, using black marking pens. The completed drawing is photographically reduced.

The negatives, which are exactly 1:1 scale, are used as etching masks. The negative for the slot side and the negative for the microstrip side are taped to opposite sides of a scrap section of dielectric. The alignment between these two negatives is done on a light table. The phase difference at port four, between signals that originate at ports one and two can be altered by poor alignment.

The section of dielectric that is to be etched is placed between the two negatives during the etching process. The completed etching is hand cut and sanded to fit the fixture.

G. COMPUTER AIDED DESIGN

A simplified version of CAD (Computer Aided Design) is used to draw the outline of the magic-tee and fin-line monopulse system (Appendix A). This process starts by establishing an imaginary "X, Y" Cartesian Grid. Every significant point that defines the drawing is assigned two grid lines. One in the X-direction and one in the Y-direction. The grid line labels start at X_a in the horizontal direction and at Y_a in the vertical direction. The origin of the grid is the point where the port three and port four microstrip lines would intersect if extended. The distances between the grid lines are defined by variables. There are numerous points on most of the grid lines, but no two points share the same horizontal and vertical grid line.

Each point which defines the drawing is numbered, starting at one, and assigned its own unique coordinates. If point one lies on the intersection of X_c and Y_v , then X_1 is set equal to X_c and Y_1 is equated with Y_v . This procedure is repeated for every point that defines the drawing.

The awkwardness of this approach is more than offset by two key advantages. First, the program that draws the magic-tee is very easy to write. The command MOVE X_1, Y_1 followed by DRAW X_2, Y_2 draws a line from point one to point two.

The second and perhaps most dramatic advantage occurs when the value of one of the variables is changed. Only one

line in the program has to be changed to adjust the width of any slot. All of the grid lines that are affected by this variable are automatically adjusted as the program is executed.

Once the program is written, this approach is faster than roughly sketching new ideas by hand. Accurate scaled drawings showing numerous variations can be completed in a few minutes without the aid of a draftsman or expensive drafting computer.

The computer program adjusts the locations of the numbered points to compensate for half of the thickness of the line that the plotter makes. There is also a few variable fudge factors that the operator can assign to any point in the program to account for anomalies introduced by the plotter. Each finished drawing is measured under a microscope. The variable that adjusts for the width of the plotter's pen and the fudge factors are adjusted at this time.

The same computer program draws the magic-tee, the fin-line horn, and the fin-line monopulse system (Appendix A). The interactive program asks the operator a string of questions. These questions include: Which drawing is to be made?; Which side (slot or microstrip) is to be drawn?; and Is it a rough draft or smooth copy? The lines on the smooth copy take considerably longer to draw but are extremely accurate (Appendix A).

The program can add a scaled three inch ruler, to the bottom of the drawing. This ruler is used to check the accuracy of the photo reduction. The ruler was only used on the first photography work order. The precision work accomplished by the Naval Postgraduate School Photo Lab is exemplary.

H. RESULTS

1. Fixture

As discussed above, the original fixture design does not provide sufficient electrical continuity between the launchers and the fixture. The flanged jacks, which attach to the modified fixture with screws, solve this problem.

The soldered joints in the fixture came apart on two occasions. Repair is extremely difficult due to the heat conducting properties of copper. The heat required to fix a seam is sufficient to loosen an adjacent joint.

Due to the flexibility of Epsilon-10, the fixture does not apply enough pressure to make good electrical contact with the port three and four microstrip. This problem is solved by soldering the launcher probes to the microstrip.

2. Magic-Tee Number One

The loop of this magic-tee tapers into the coupled slot region. The second magic-tee does not have this taper. Other than that, the first two magic-tees are identical.

The first magic-tee was destroyed in testing. The soldered connection on port four ripped the microstrip off of the dielectric when the screws that attach the launcher to the fixture were tightened.

Preliminary reflection checks on a scalar analyzer were performed prior to this damage. The reflections for this magic-tee are slightly worse than the similar reflections in the second magic-tee.

3. Magic-Tee Number Two

The slots that lead to ports one and two in this magic-tee are 0.01 inches inside of the fixture wall. The actual scattering matrix for this device is illustrated in Figure 16. The reflections in this magic-tee are quite high.

The phase shifts are almost perfect, except for a slight phase error associated with port four. This is probably caused by improper alignment of the two negatives prior to the etching process.

4. Magic-Tee Number Three

The closeness of the port one and two slots to the fixture wall in the second magic-tee causes an apparent discontinuity where the fixture terminates. These slots were set well inside the fixture on the third magic-tee in hopes of eliminating this discontinuity.

The actual scattering matrix for the third magic-tee is shown in Figure 17. This magic-tee also has near perfect

phase shifts. However, the reflections are a little higher than they were for magic-tee number two.

The actual phase and magnitude from 8- to 12-GHZ for each of the 16 points in magic-tee number three's scattering matrix are illustrated in graphical form in Figures 18 to 33.

IV. FIN-LINE MONOPULSE SYSTEM

A. DESIGN

The fin-line monopulse system is a combination of fin-line magic-tee number three and two of the fin-line horns developed by Hsu in Reference 5. The horns are driven from ports one and two of the magic-tee. The width of the slot in the horns is the same width as the matching slots in the magic-tee. The half wave length geometry of the fin-line horn and fin-line magic-tee are maintained in the fin-line monopulse system (Fig. 34). The monopulse system is drawn at a 2:1 scale. The HP-9872C Plotter will not accommodate a larger drawing.

All of the exposed edges of the dielectric, except the actual horn openings, are sealed with copper tape. This prevents energy from leaking out of the slots and destroying the antenna patterns.

The distance between the center of the two horns is 30.44 millimeters. At 10.3-GHZ, this distance is equal to 1.05 wavelengths in air and 3.34 wavelengths in Epsilon-10. The antennas use both air and dielectric to propagate the antenna pattern. Therefore, the effective element spacing of the fin-line monopulse system is between the limits of 1.05 and 3.34 wavelengths at 10.3-GHZ.

The E-plane pattern for a single fin-line horn with a dielectric constant of 10.2 is illustrated in Figure 6. The associated H-plane pattern is shown in Figure 35. The extreme width of the H-plane pattern is due to the high dielectric constant of 10.2. Similar horns constructed with a dielectric constant of 2.54, have nearly symmetrical E- and H-plane patterns [Ref. 5]. The monopulse effect of this system is entirely in the E-plane. Therefore, the wide H-plane element pattern will produce a wide H-plane monopulse system pattern.

The gain of each antenna is obtained by comparing the amplitude of the antenna pattern with the pattern from a standard gain horn.

B. RESULTS

The actual E- and H-plane patterns for the monopulse system are shown in Figures 36 and 37 respectively. The gain of the sum pattern is eight dB. This is four dB above the element pattern. A three dB improvement is expected (Fig. 9).

The first nulls in the sum pattern (Fig. 36) are approximately 29 degrees left and right of boresight. The element spacing in the computer simulated sum pattern (Fig. 38) is adjusted until the first nulls occur at plus and minus 29 degrees. The corresponding simulated difference pattern is shown in Figure 39. The effective element spacing that produces this match is 1.60 wavelengths.

The difference port microstrip was torn off of the dielectric during testing. This occurred after the patterns in Figures 36 and 37 were taken. The damage was repaired by soldering a small section of copper foil across the break.

Following this repair, the fin-line monopulse system was tested, in an effort to find the bottom of the difference null. Figure 40 shows the results of this test. The recorder gain is maximum, and the eight dB sum pattern is saturated against the top of the recorder. Yet, the bottom of the difference null is still not visible.

V. CONCLUSIONS AND RECOMMENDATIONS

A. FIXTURE

1. Conclusions

The original fixture design is unsatisfactory. It is too fragile and it does not provide good electrical continuity between the magic-tee and the launchers at ports three and four. The modified fixture, which has screwed on coaxial to microstrip launchers at ports three and four, is marginally effective.

The electrical transitions through the fixture wall at ports three and four do not appreciably restrict the bandwidth of the fin-line magic-tee (Figs. 18-33). Therefore, the holes in the fixture at ports three and four and the notches in the magic-tee's ground plane at ports three and four function reasonably well.

2. Recommendations

Testing should not be resumed until an improved fixture is constructed. Each half of the new fixture should be machined out of a solid piece of metal. All of the launchers which connect to the fixture should be attached with screws. A stiff or semi-rigid dielectric should be used to avoid the necessity of soldering the launchers to the microstrip lines. The microstrip to coaxial transition

concept which is used in this thesis should be incorporated in the new fixture design.

B. FIN-LINE MAGIC-TEE

1. Conclusions

The fin-line magic-tee worked better than expected after only three iterations of the developmental process. The phase shifts are very close to the theoretical parameters. However, the dielectric material is too flexible and the reflections at all four ports need to be reduced.

There are four factors that could be causing the high reflections. First, as noted in the engineering approximations (Chap. 3), the bilateral fin-line impedance of the loop might be slightly above the desired 100 ohms.

Second, the soldered connections on the microstrip lines at ports three and four probably introduce significant reflections.

Third, the magic-tee is not completely symmetric. The port three microstrip line couples with two slots while the microstrip at port four couples with a single slot.

Fourth, due to the different dielectric constants of air and Epsilon-10, the distribution of the electric field within the dielectric is not the same as the distribution of the electric field in the air. Therefore, the reactive interference in the air is not the same as the reactive interference within the dielectric material. These unmatched reactances probably contribute to the harmonic pattern of reflections observed at all four ports (Figs. 18-33).

2. Recommendations

Future magic-tees should be made out of a stiff or semi-rigid dielectric material. The combination of a stiffer material and a new fixture design should eliminate the need for soldered connections.

Two new magic-tees should be made with unilateral loop impedances of 190 ohms and 195 ohms. Tests of these tees will help identify the proper unilateral loop impedance and check the accuracy of the first engineering approximation.

Two sections of dielectric material which are totally void of metal foil can be added to the outsides of the existing two sections of dielectric. In this configuration, the slots will be totally surrounded by the same dielectric constant. This should improve the symmetry of the electric field distribution near the slots, thereby reducing the amount of reflected energy within the magic-tee.

C. FIN-LINE MONOPULSE SYSTEM

1. Conclusions

The performance of the fin-line monopulse system is very satisfactory. The null in the difference pattern is more than 40 dB below the peak of the sum pattern at 10.3-GHZ (Fig. 40). This deep unmeasurable null which exactly splits the main peak of the sum pattern (Fig. 40) is the essence of a good monopulse antenna. The minor problems

caused by high reflections should be resolved when the fin-line magic-tee is improved.

The peak in the fin-line monopulse system's difference pattern is approximately nine dB lower than the peak in it's sum pattern (Fig. 36). This difference is approximately three dB more than the corresponding relationship in Skolnik's patterns [Ref. 7: pp. 17-23]. The fin-line comparator's weak difference pattern is probably the result of reflections caused by the large quantities of solder on the port four microstrip line. The shape of the fin-line monopulse system's sum and difference patterns and the exact centering of the difference null are almost identical to Skolnik's illustrations.

Skolnik [Ref. 7: pp. 10-28] shows that the second null in a theoretical sum pattern is not present on an actual monopulse pattern. This effect is roughly reproduced in this thesis (Figs. 36 and 38). The second and third peaks in the simulated sum pattern (Fig. 38) are at 40 and 72 degrees respectively. Corresponding peaks are evident at 50 and 77 degrees on the actual pattern (Fig. 36). The actual pattern is filled in between these two peaks just as Skolnik predicted.

As discussed in Chapter Four, the effective element spacing at 10.3-GHZ is 1.60 wavelengths. This is 152% of the element spacing in air and 48% of the element spacing in the dielectric. These percentages are probably a function of the

dielectric constant. Therefore, the effective element spacing of the fin-line monopulse system can probably be controlled by proper selection of the dielectric constant.

2. Recommendations

The fin-line monopulse system should be enlarged to include two orthogonal difference ports. This will make it useful as a target tracking antenna [Ref. 7: pp. 10-23]. The diamond configuration shown in Figure 4 and the square design illustrated in Figure 5 can both be adapted to the fin-line monopulse technique.

a. Diamond Fin-Line Monopulse System

A simple arrangement of four horns connected to three fin-line magic-tees can be constructed using a semi-rigid dielectric material. This configuration will consist of two of the fin-line monopulse comparators developed in this thesis placed side by side. The difference ports of these two comparators will be the elevation and the azimuth ports for the new three port system. The sum ports will connect to the inputs of the third magic-tee. The third magic-tee's sum port will be the system's sum port. The difference port of the third magic-tee will be loaded.

The individual azimuth and elevation comparators will be electrically orthogonal to each other if they are each twisted 45 degrees in opposing directions. The twisting should be confined to the area between the fixture and the horns. In this configuration the two groups of antennas will

be orthogonal to each other, yet all three magic-tees will be in the same plane.

b. Square Fin-Line Monopulse System

A dual plane fin-line monopulse system constructed out of semi-rigid dielectric material is illustrated in Figure 41. The dielectric material will have to be flexible enough to bend, yet rigid enough to provide good electrical contact between the microstrip lines and the launchers. This device will require careful engineering to properly align the sheets of dielectric material. Once these problems are solved, mass production should be easy.

D. COMPUTER AIDED DESIGN

1. Conclusions

The computer aided design portion of this thesis is useable, however it should be enlarged to include more of the design process.

2. Recommendations

Figures 12, 13, and 14 should be modified to include a wider range of dielectric constants and dielectric thicknesses. The data in the new versions of Figures 12 and 13 can probably be represented by simple algebraic equations [Ref. 10: pp. 226-228]. The new version of Figure 14 could be approximated by exponential equations. The four step trial and error process presented in Chapter Three and the design parameters for the fin-line horns [Ref. 5] can probably be written in the form of a short computer program.

information should be computerized and added to the existing program (Appendix A).

The improved version of the computer aided design program could ask the operator; What gain/beam width combination is desired for the fin-line monopulse system? The program could then recommend the appropriate dielectric constant and prompt the operator to place the paper on the plotting table. When the first drawing is finished, the program could prompt the operator to change the paper. Using this concept, made-to-order monopulse target tracking antennas could be inexpensively mass produced in a matter of days.

E. MEETING THESIS OBJECTIVES

Magic-tees number two and three and the monopulse system satisfy the first objective listed in the introduction. The sum and difference patterns (Figs. 36, 37, and 40) are better than expected for limited iterations of the design process. They meet the second objective. The interactive computer aided design program (Appendix A) satisfies the third objective. The recommendations presented in this chapter fulfill the final objective of this thesis.

APPENDIX A

COMPUTER PROGRAM LISTING

MSEE THESIS

FIN-LINE MAGIC TEE, FIN-LINE HORN AND
FIN-LINE MONOPULSE SYSTEM

BY LCDR JAMES W. ROWLEY

AUGUST 1985

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA.

(WRITTEN ON AN HP-9845B; WITH AN HP-9872C PLOTTER)

MISC. PROGRAMING INFO:

THIS PROGRAM IS WRITTEN IN "BASIC". THE FOLLOWING RULES APPLY:

BUILT IN COMMANDS: THE ENTIRE WORD IS IN UPPER CASE LETTERS.

DEFINITION OF NON-STANDARD BUILT IN COMMANDS:

ATN(): RETURNS THE ARC TANGENT OF THE VARIABLE IN THE BRACKETS.

MSCALE A,B: PLOTTER IS SCALED IN MILLIMETERS. THE ORIGIN IS

"A" MILLIMETERS LEFT AND "B" MILLIMETERS UP FROM THE LOWER

LEFT HAND CORNER OF THE PLOTTING AREA. WHEN "MSCALE" IS

USED, ALL UNLABLED UNITS IN THE PROGRAM ARE IN MILLIMETERS.

PLOTTER IS ": COORDINATES THE COMPUTER AND THE PLOTTER.

DEG: TELLS THE COMPUTER THAT ALL ANGLES ARE IN DEGREES.

VARIABLES: ONE UPPERCASE LETTER FOLLOWED BY NOTHING, OR FOLLOWED

BY A STRING OF LOWERCASE LETTERS AND/OR NUMBERS. A VARIABLE

CAN BE UP TO 15 CHARACTERS LONG. IF A VARIABLE IS ENDED IN A

DOLLAR SIGN (\$), IT IS A STRING VARIABLE. DUE TO THE EXTREMELY

LARGE NUMBER OF VARIABLES IN THIS PROGRAM, THEY ARE DEFINED AND

ASSIGNED INITIAL VALUES AT THE SAME TIME. THIS PROGRAM DEFINES

KEY POINTS IN TERMS OF "X" AND "Y" REFERENCE PLANES. THESE PLANES

ARE DEFINED BY A COMBINATION OF A FEW KEY DIMENSIONS. THIS CHANGE

OF VARIABLES APPROACH WAS USED TO FACILITATE FUTURE DESIGN

MODIFICATIONS. A FOLLOW ON PROGRAMER CAN CHANGE ANY ONE OR MORE

OF THE KEY DIMENSIONS IN THIS PROGRAM AND THE ENTIRE DRAWING WILL

BE AUTOMATICALLY ADJUSTED. THIS IS A LIMITED APPLICATION OF CAD

(COMPUTER AIDED DESIGN).

I STEP ONE: DETERMINE WHICH DRAWING THE OPERATOR DESIRES.

INPUT "MAGIC-TEE (TEE); HORN (HORN); OR MONOPULSE SYSTEM (MONO)?",Drawing\$

IF Drawing\$="TEE" THEN 500

IF Drawing\$="HORN" THEN 500

IF Drawing\$="MONO" THEN 500

GOTO 450 IASK QUESTION UNTIL PROPER REPLY IS GIVEN.

INPUT "DRAW FIN-LINE OR MICROSTRIP SIDE? (F/M),CONT",Side\$

IF Side\$="F" THEN 550

IF Side\$="M" THEN 550

GOTO 500IWRONG REPLY.

I

INPUT "DRAW RULER AND COMMENTS? (Y/N),CONT",Ruler\$

IF Ruler\$="Y" THEN 600ICHECK FOR PROPER REPLY.

IF Ruler\$="N" THEN 600

GOTO 550 IASK QUESTION UNTIL PROPER REPLY IS GIVEN.

I

INPUT "QUICK LINE (1), OR PRECISION LINE (4)",Linenum

IF Linenum=1 THEN 660

IF Linenum=4 THEN 640

GOTO 600IASK UNTIL VALID REPLY GIVEN.

Segmentsize=.04 IDISTANCE BETWEEN THE DOTS, IF A DOTTED LINE IS USED.

I

I STEP TWO: ADJUST THE GENERAL LAYOUT OF THE DRAWING.

```

670 |
680 | THIS SECTION CONTAINS REQUIRED COMMANDS FOR COMPUTER/PLOTTER
690 | COORDINATION AND GENERAL COMMANDS AND VARIABLES THAT ARE
700 | USED TO ORGANIZE THE DRAWING.
710 | PLOTTER IS "9872A" | COORDINATES COMPUTER AND PLOTTER.
720 | DEG | ALL ANGLES IN THE PROGRAM ARE IN DEGREES.
730 | Title$="3" | THIS WILL BE PRINTED ON THE DRAWING.
740 | Flip=1 | -1 PUTS THE SUM NOTCH ON THE OPPOSITE SIDE.
750 | Xcenter=82 | CENTER OF DRAWING ON PAGE IN mm FROM LOWER LEFT.
760 | Ycenter=95 | CENTER OF DRAWING ON PAGE IN mm FROM LOWER LEFT.
770 | MSCALE Xcenter,Ycenter | POSITIONS THE DRAWING ON THE PAPER,
780 | Scale=1 | THE ENTIRE DRAWING IS SCALED TO THIS FACTOR.
790 | Mm=Scale | DEFINES Mm=MILLIMETERS (DRAWN TO SCALE).
800 | In=25.4*Scale | DEFINES In=25.4 MILLIMETERS = INCH (DRAWN TO SCALE).
810 | LINE TYPE Linenum,Segmentsize
820 | | IF Linenum EQUALS "1", THE PLOTTER WILL DRAW
830 | | A REGULAR LINE. IF Linenum EQUALS "4", THE
840 | | PLOTTER WILL DRAW A DOTTED LINE WITH OVERLAPPING
850 | | DOTS. THE DOTTED LINE ELIMINATES PEN OSCILLATION
860 | | ERRORS, AND PRODUCES A VERY HIGH QUALITY SOLID LINE.
870 |
880 |
890 | STEP THREE: DEFINE THE DIMENSIONS OF THE DRAWING.
900 | ;
910 | *THE FOLLOWING VARIABLES DESCRIBE THE ENTIRE DRAWING. THE REST OF THE
920 | PROGRAM USES THESE VALUES TO CONSTRUCT THE DRAWINGS.
930 | ANY CHANGE IN THESE VARIABLES WILL RESULT IN ALL ASSOCIATED PARAMETERS
940 | IN THE DRAWING BEING ADJUSTED AUTOMATICALLY.
950 | | VARIABLES ASSOCIATED WITH THE MAGIC TEE END IN A "t" SUBSCRIPT.
960 | | VARIABLES ASSOCIATED WITH THE SINGLE HORN END WITH AN "h" SUBSCRIPT.
970 | | VARIABLES ASSOCIATED WITH THE MONOPULSE SYSTEM END IN AN "mh"
980 | | SUBSCRIPT.
990 |
1000 |
1010 | USER DEFINED VARIABLES:
1020 |
1030 | Er=10.2 | DIELECTRIC CONSTANT. Er IS ONLY USED
1040 | | TO CALCULATE THE TEM WAVELENGTH IN
1050 | | THE MICROSTRIP LINES.
1060 | Lambdazero=26.306*Mm | FREE SPACE WAVELENGTH AT 11.4 GHZ.
1070 | Lambdad=Lambdazero/SQR(Er) | TEM WAVELENGTH.
1080 | Qucoupledslots=.4998*Lambdazero/4 | QUARTER WAVELENGTH IN COUPLED SLOTS.
1090 | | .4998 IS 97% OF THE VALUE FOR A
1100 | | SINGLE SLOT THAT IS NOT COUPLED.
1110 | Qwloop=.6368*Lambdazero/4 | QUARTER WAVELENGTH IN LOOP SLOTS.
1120 | Qwmicrostrip=Lambdad/4 | QUARTER WAVELENGTH IN MICROSTRIP (TEM).
1130 | Qwhornslot=.5216*Lambdazero/4 | QUARTER WAVELENGTH IN 100 OHM SLOTS.
1140 |
1150 | THE FOLLOWING DIMENSIONS ARE EXACTLY MATCHED TO THE SIZE OF THE FIXTURE;
1160 | At=.165*In | WIDTH OF THE NOTCH IN THE COPPER FOIL THAT MATCHES THE
1170 | | HOLE IN THE FIXTURE THAT CONNECTS THE DEVICE TO THE
1180 | | COAXIAL LAUNCHER.
1190 | Bt=.0238*In | WIDTH OF THE MICROSTRIP TRANSITION AND OF THE WIDTH
1200 | | OF THE CENTER CONDUCTOR IN THE COAXIAL ADAPTER.
1210 | Ct=.03*In | THICKNESS OF THE FIXTURE WALL THAT IS BEYOND THE
1220 | | SUBSTRATE GROOVE.
1230 | Dt=.22*In | DISTANCE FROM CENTER OF DIFFERENCE PORT TO THE EDGE
1240 | | OF THE DIELECTRIC THAT IS INSIDE OF THE FIXTURE.
1250 | Et=.770*In | LEFT EDGE OF THE SUBSTRATE TO THE CENTER OF SUM PORT.
1260 | | THIS VALUE MAKES THE SUM AND DIFFERENCE PORTS
1270 | | APPROXIMATELY THE SAME LENGTH.
1280 | Ft=1.5*In | CENTER OF SUM THE PORT TO THE RIGHT EDGE OF THE FIXTURE.
1290 | | THIS ALLOWS SUFFICIENT ROOM TO MOUNT THE FIXTURE
1300 | | WHILE TAKING ANTENNA PATTERNS.
1310 | Grt=.5*In | ALLOWS ROOM FOR LAUNCHERS ON RIGHT SIDE OF PORTS 1&2.
1320 | Glt=.25*In | ALLOWS ROOM FOR LAUNCHERS ON LEFT SIDE OF PORTS 1&2.

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1330 |
1340 | THE FOLLOWING DIMENSIONS DEFINE THE LAYOUT OF THE MAGIC TEE;
1350 | THREE DIFFERENT VALUES FOR Ht ARE GIVEN. PICK THE APPROPRIATE ONE.
1360 | Ht=1.3117*Mm !WIDTH OF 160 OHM LOOP SLOT.
1370 | Ht=1.674*Mm !WIDTH OF 180 OHM LOOP SLOT.
1380 | Ht=2.056*Mm !WIDTH OF 200 OHM LOOP SLOT.
1390 | It=.340*Mm !WIDTH OF THE COUPLED SLOTS.
1400 | Jt=.43995*Mm !WIDTH OF THE 100 OHM "HORN" SLOTS.
1410 | Kt=.2086*Mm !WIDTH OF MICROSTIP.
1420 | Lt=.0781*In !LENGTH OF THE TRANSITION IN THE SUM AND DIFFERENCE
1430 | MICROSTIP LINES.
1440 | Mt=2.54*Mm !DISTANCE BETWEEN THE SLOTS IN THE LOOP.
1450 | Nt=Ht+Mt/2-(It+Ot/2) !MAKES ANGLE BETWEEN PTS 36,37 AND 38 135 DEGS.
1460 | Ot=.266*Mm !DISTANCE BETWEEN COUPLED SLOTS.
1470 | Pt=1.5*Mm !WIDTH OF THE ISOLATION SLOT.
1480 | Qt=.8*(Dt-Jt) !MAKES THE PARALLEL SLOTS 1/4 WAVELENGTH APART AND
1490 | ! AND HALF A WAVELENGTH FROM FIXTURE WALLS AT 11.4 GHZ.
1500 | Rt=.25*In !DISTANCE BETWEEN FIXTURE AND FIRST CORNER IN SLOTS.
1510 | St=.2*In !DISTANCE FROM FIXTURE TO VERTICAL SLOTS.
1520 | IF Rt+.1*In>St THEN St=Rt+.1*In !ALLOWS ROOM FOR LOWER BAND IN THE
1530 | ! IN THE INPUT SLOTS (OUTSIDE OF FIXTURE).
1540 | Tt=.3*In !SIDE OF 45 DEGREE CUTOUT.
1550 | Ut=0*In !LENGTH OF VERTICAL SLOTS.
1560 | Vt=15*Mm !HALF OF THE SEPARATION BETWEEN THE "HORN" SLOTS.
1570 | ! THE NEXT LINE INSURES ADEQUATE SEPARATION BETWEEN THE TIPS OF THE
1580 | ! MICROSTRIP THAT EXTENDS FROM PORTS ONE AND TWO.
1590 | IF Vt<.35*In THEN Vt=.35*In
1600 | Wt=.5*In !DISTANCE FROM "HORN" SLOTS TO EDGE OF DIELECTRIC.
1610 | ! THIS ALLOWS SUFFICIENT ROOM TO MOUNT THE LAUNCHERS.
1620 |
1630 | ! THE FOLLOWING LINES DEFINE THE HORN.
1640 | Angleh=9.1 !HALF OF THE HORN ANGLE.
1650 | Nh=8 !Nh*Lambdad=LENGTH OF HORN FLARE (Bh).
1660 |
1670 | ! THE FOLLOWING DIMENSIONS ARE USED TO ADD THE MISC. DATA TO THE DRAWING.
1680 | Sixteenth=1/16*In !USED TO BUILD RULER AT THE BOTTOM OF THE DRAWING.
1690 | Space=.07*In !SPACES THE COMMENTS AND RULER AWAY FROM THE DRAWING.
1700 |
1710 |
1720 | ! THE FOLLOWING VARIABLES ARE COMBINATIONS OF THE USER DEFINED VARIABLES,
1730 | ! AND/OR SHORT VARIABLES THAT REPLACE LONGER MORE DESCRIPTIVE VARIABLES.
1740 |
1750 | Bat=Qumicrostrip !LENGTH OF MICROSTRIP OVERLAPS.
1760 | Bbt=Qwhornslot !LENGTH OF HORN SLOT OVERLAP.
1770 |
1780 | ! THERE ARE TWO VALUES FOR Bct AND Bdt GIVEN. ONE SET MAKES A TAPERED
1790 | ! LOOP, AND THE OTHER SET MAKES A NON-TAPERED LOOP AS INDICATED. PICK
1800 | ! THE DESIRED TYPE OF LOOP GEOMETRY.
1810 |
1820 | ! TAPERED LOOP:
1830 | ! Angle0 IS THE ANGLE USED TO DETERMINE Bct AND Bdt. IT IS ONE HALF OF THE
1840 | ! AVERAGE OF THE TWO ANGLES FORMED BY POINTS 20,21,22 AND 36,37,38. Bct
1850 | ! AND Bdt ARE USED TO MAKE A SMOOTH TRANSITION AROUND THE CORNERS IN
1860 | ! THE LOOP.
1870 | ! Angle0=((180-ATH((Ht+Mt/2-It-Ot/2)/Ht)))/2+((180-ATH((Ht/2-Ot/2)/Ht))/2)/2
1880 | ! Bct=Ht/TAN(Angle0) !THE OFFSET AT THE RIGHT SIDE OF THE TAPERED LOOP.
1890 | ! Bdt=It/TAN(Angle0) !OFFSET AT EDGE OF TAPERED LOOP.
1900 |
1910 | ! NON-TAPERED LOOP:
1920 | Angle00=ATH(Ht/(Ht+Mt/2-(It+Ot/2))) !FOR NON-TAPERED LOOP.
1930 | Bct=Ht*TAN(45-Angle00/2) !FOR NON-TAPERED LOOP.
1940 | Bdt=Ht/COS(Angle00)-It*TAN(Angle00) !FOR NON-TAPERED LOOP.
1950 |
1960 |
1970 | Bet=Jt/COS(45)-It !OFFSET AT LEFT EDGE OF COUPLED SLOTS.
1980 | Bft=Qucoupledslots-Bet/2-Bdt/2 !LENGTH OF THE TOP OF THE COUPLED SLOTS.

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1990 Bgt=TAN(22.5)*Jt      ! OFFSET FOR 45 DEGREE BENDS IN 100 OHM SLOTS.
2000 !
2010 !
2020 ! THE FOLLOWING CALCULATIONS MAKE THE CENTERLINE OF THE LOOP 3/4 OF A
2030 ! WAVELENGTH LONG.
2040 Arc=(Mt+Ht)*PI/4-Kt/2 ! ARC LENGTH, EXCLUDING PORTION THAT OVERLAPS THE
2050 ! MICROSTRIP.
2060 Slantpartofloop=SQR((Mt+Bct/2-Bdt/2)^2+((Mt+Ht-Qt-It)/2)^2) ! LENGTH OF THE
2070 ! SLANT PART OF
2080 ! THE LOOP,
2090 ! MEASURED ON
2100 ! CENTERLINE.
2110 Flatpartofloop=3*Quloop-Arc-Slantpartofloop-Bdt/2 ! ADJUSTABLE PART OF LOOP.
2120 Bht=Flatpartofloop+Bct/2 ! THIS MAKES THE LOOP 3/4 OF A WAVELENGTH LONG.
2130 !
2140 Bit=Dt-Qt-It-Qt/2 ! LENGTH OF 45 DEG SLOTS (IN THE "X" AND "Y" DIRECTIONS)
2150 ! THAT ARE INSIDE OF THE FIXTURE.
2160 Bjt=Dt-Qt-Jt ! DISTANCE FROM CENTERLINE TO INPUT SLOTS (INSIDE OF
2170 ! OF THE FIXTURE).
2180 Bkt=St-Rt ! LENGTH OF LOWER 45 DEGREE SECTION (IN "X" AND "Y"
2190 ! DIRECTION) THAT IS OUTSIDE OF THE FIXTURE.
2200 Bit=Vt-Bjt-Bkt-Qt ! LENGTH OF UPPER 45 DEGREE SECTION (IN THE "X" AND "Y"
2210 ! DIRECTION) THAT ARE OUTSIDE OF THE FIXTURE.
2220 Bmt=2^.5*(Dt-Qt-Jt-Pt/2)-Qt/2 ! DISTANCE FROM COUPLED SLOTS TO THE
2230 ! TIP OF THE ISOLATION SLOT (IN THE "X"
2240 ! DIRECTION).
2250 ! (IN THE "X" AND "Y" DIRECTIONS).
2260 Bnt=Pt/2 ! LENGTH OF THE VEE AT THE END OF THE ISOLATION SLOT.
2270 ! Bnt KEEPS THE SLANT PORTION OF THE ISOLATION SLOT
2280 ! AND THE HORIZONTAL PART OF THE ISOLATION SLOT
2290 ! EQUADISTANCE FROM THE 100 OHM SLOTS (INSIDE OF THE
2300 ! FIXTURE).
2310 !
2320 ! THE FOLLOWING ARE COMBINATIONAL HORN VARIABLES.
2330 IF Drawings$="HORN" THEN 2360 ! USED TO MATCH HORN TO FIXTURE.
2340 Ah=Qt ! WIDTH OF HORNS MATCHES FIXTURE FOR MAGIC-TEE.
2350 GOTO 2370
2360 Ah=Dt-Jt/2 ! WIDTH OF HORN STRIP FOR SINGLE HORN.
2370 Bh=Nh*Lambdad ! LENGTH OF HORN FLARE FROM Xoh.
2380 Ch=Ah*SIN(Angleh) ! LATERAL OFFSET DISTANCE AT END OF HORN.
2390 Dh=Ah*COS(Angleh) ! VERTICAL OFFSET DISTANCE AT END OF HORN.
2400 Eh=Bh*SIN(Angleh) ! HALF OF HORN APERTURE.
2410 Fh=Bh*COS(Angleh) ! HORIZONTAL LENGTH OF HORN FROM Xoh.
2420 !
2430 !
2440 ! THE FOLLOWING LINE PLACES A CONDITION ON THE LENGTH OF Glt. THIS IS
2450 ! DONE TO ALLOW SUFFICIENT ROOM BETWEEN THE MICROSTRIP CROSSING POINT,
2460 ! AND THE 45 DEGREE BEND IN THE SLOT TO THE LEFT OF THE MICROSTRIP.
2470 IF Glt<St+Jt+Bit+5*Mm THEN Glt=St+Jt+Bit+5*Mm
2480 !
2490 !
2500 ! STEP FOUR: DEFINE "X" AND "Y" PLANES IN TERMS OF VARIABLES LISTED ABOVE.
2510 ! ALL OF THE POINTS THAT WILL BE USED TO DEFINE THE DRAWING
2520 ! SHOULD BE ON THE INTERSECTION OF TWO OF THESE PLANES. OTHER
2530 ! POINTS CAN BE DRAWN TOO, BUT ONLY IF THEY ARE DEFINED WITHIN
2540 ! THE "DRAW" COMMAND (THIS SHOULD BE AVOIDED, AS IT WILL DESTROY
2550 ! THE "CAD" ASPECT OF THIS PROGRAM).
2560 !
2570 Xot=0 ! SETS LOCATION OF DRAWING WITH RESPECT TO THE ORIGIN.
2580 Xat=Xot-Et-Ct ! LEFT EDGE OF DIFFERENCE PORT.
2590 Xbt=Xot-Et ! LEFT EDGE OF THE DIELECTRIC WITHIN THE FIXTURE.
2600 Xct=Xbt+Lt ! TIP OF THE DIFFERENCE NOTCH.
2610 Xdt=Xot-Kt/2-Nt-Bht ! CENTER OF THE LOOP HALF CIRCLE.
2620 Xet=Xdt-Mt/2+Bt ! EDGE OF DIFFERENCE MICROSTRIP.
2630 Xft=Xdt+Bht-Bct ! LOWER LEFT LOOP CORNER.
2640 Xgt=Xdt+Bht ! UPPER LEFT LOOP CORNER.

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2650	Xht=Xot-At/2	!LEFT EDGE OF THE TAB OF DIELECTRIC ON THE SUM PORT.
2660	Xlt=Xot-Bt/2	!LEFT EDGE OF SUM MICROSTRIP TRANSITION.
2670	Xjt=Xot-Kt/2-Bdt	!LOWER RIGHT LOOP CORNER.
2680	Xkt=Xot-Kt/2	!LEFT EDGE OF SUM MICROSTRIP.
2690	Xlt=Xot+Kt/2	!RIGHT EDGE OF SUM MICROSTRIP.
2700	Xmt=Xot+Bt/2	!RIGHT EDGE OF SUM MICROSTRIP TRANSITION.
2710	Xnt=Xot+At/2	!RIGHT EDGE OF THE TAB OF DIELECTRIC ON THE SUM PORT.
2720	Xpt=Xot-Kt/2+Bft	!UPPER RIGHT EDGE OF COUPLED SLOTS.
2730	Xqt=Xpt+Bft	!LOWER RIGHT EDGE OF COUPLED SLOTS.
2740	Xrt=Xpt+Bt	!UPPER LEFT EDGE OF "INPUT" SLOTS.
2750	Xst=Xrt+Bgt	!LOWER LEFT EDGE OF "INPUT" SLOTS.
2760	Xtt=Xqt+Bmt	!LEFT TIP OF THE ISOLATION SLOT.
2770	Xut=Xtt+Bnt	!START OF ISOLATION SLOT TIP.
2780	Xvt=Xot+Ft	!RIGHT EDGE OF THE FIXTURE.
2790	Xwt=Xvt+Rt	!UPPER RIGHT EDGE OF "INPUT" SLOT.
2800	Xxt=Xwt+Bgt	!LOWER RIGHT EDGE OF "INPUT" SLOT.
2810	Xyt=Xvt+Tt	!TOP OF 45 DEGREE CUTOUT.
2820	Xzt=Xvt+St	!LEFT SIDE OF VERTICAL SLOT.
2830	Xaat=Xzt+Jt	!RIGHT SIDE OF VERTICAL SLOT.
2840	Xabt=Xaat+Blt-Bgt	!LEFT EDGE OF UPPER SLOT CORNER.
2850	Xact=Xaat+Blt	!RIGHT EDGE OF UPPER SLOT CORNER.
2860	Xadt=Xvt+Glt	!LEFT EDGE OF INPUT NOTCH.
2870	Xaet=Xadt+At/2-Bt/2	!LEFT EDGE OF INPUT TRANSITION.
2880	Xaft=Xadt+At/2-Kt/2	!LEFT EDGE OF INPUT MICROSTRIP.
2890	Xagt=Xadt+At/2	!CENTER OF INPUT NOTCH.
2900	Xaht=Xagt+Kt/2	!RIGHT EDGE OF INPUT MICROSTRIP.
2910	Xait=Xagt+Bt/2	!RIGHT EDGE OF INPUT TRANSITION.
2920	Xajt=Xadt+At	!RIGHT EDGE OF INPUT NOTCH.
2930	Xakt=Xaht+Bbt	!RIGHT END OF SLOTS.
2940	Xalt=Xajt+Grt	!RIGHT EDGE OF DIELECTRIC.
2950	!	
2960	!	
2970	Xoh=Xvt+Ch-Jt/(2*TAN(Angleh))	!APEX OF HORN OPENING ANGLE
2980		! REFERENCED TO EDGE OF FIXTURE.
2990	Xah=Xoh+Fh	!OUTER EDGE OF HORN OPENING.
3000	Xbh=Xah-Ch	!UPPER OUTER EDGE OF HORN.
3010	Xch=Xoh+Jt/(2*TAN(Angleh))	!HORN MOUTH.
3020	Xdh=Xch-Ch	!HORN/FIXTURE JOINT.
3030	Xeh=Xkt-Bbt	!END OF HORN SLOT.
3040	!	
3050	!	
3060	Xwmh=Xwt-TAN(22.5)*Lambdad/2	!USED TO MOVE X34t LEFT TO X34mh.
3070	Xxmh=Xxt+Lambdad*(SQR(.5)-.125)	!MOVES X25t RIGHT TO X25mh.
3080	Xzmh=Xzt-Lambdad/2	!USED TO MOVE X32t/X33t LEFT TO X32mh/X33mh.
3090	Xaamh=Xaat+Lambdad/2	!USED TO MOVE X26t/X27t RIGHT TO X26mh/X27mh.
3100	Xabmh=Xabt-TAN(22.5)*(Lambdad/2)	!USED TO MOVE X31t LEFT TO X31mh.
3110	Xacmh=Xact+TAN(22.5)*(Lambdad/2)	!USED TO MOVE X28t RIGHT TO X28mh.
3120	!	
3130	!	
3140	Yot=0	
3150	Yat=Yot+Yt+Jt+Wt	!TOP OF THE DIELECTRIC.
3160	Ybt=Yat-(Ct+Lt)	!TIP OF INPUT NOTCH.
3170	Yct=Yat-Tt	!BOTTOM OF 45 DEGREE CUTOUT.
3180	Ydt=Yot+Yt+Jt	!UPPER EDGE OF THE HORN SLOT.
3190	Yet=Yot+Yt	!LOWER EDGE OF THE HORN SLOT.
3200	Yft=Yet-Blt+Bgt	!UPPER EDGE OF THE UPPER SLOT CORNER.
3210	Ygt=Yet-Blt	!LOWER EDGE OF THE UPPER SLOT CORNER.
3220	Yht=Yot+Dt+Ct	!TOP EDGE OF SUM PORT DIELECTRIC.
3230	Ylt=Yet-Bat	!END OF PORT ONE MICROSTRIP.
3240	Yjt=Yot+Dt	!TOP OF DIELECTRIC IN THE FIXTURE.
3250	Ykt=Yot+Bjt+Bkt+Bgt	!UPPER EDGE OF LOWER SLOT CORNER.
3260	Ylt=Ykt-Bgt	!LOWER EDGE OF LOWER SLOT CORNER.
3270	Ymt=Yjt-Lt	!TIP OF SUM NOTCH.
3280	Ynt=Yot+At/2	!TOP EDGE OF THE DIFFERENCE PORT DIELECTRIC TAB.
3290	Ypt=Yot+Mt/2+Ht	!TOP EDGE OF THE SLOT IN THE LOOP.
3300	Yqt=Yjt-Qt	!TOP EDGE OF THE INPUT SLOT.

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3310 Yrt=Yjt-Qt-Jt      ILOWER EDGE OF THE INPUT SLOT.
3320 Yst=Yot+Mt/2      ILOWER EDGE OF THE LOOP SLOT.
3330 Ytt=Yot+Pt/2      ITOP EDGE OF THE ISOLATION SLOT.
3340 Yut=Yot+Ot/2+It    IUPPER EDGE OF THE COUPLED SLOT.
3350 Yvt=Yot+Bt/2      IUPPER EDGE OF THE DIFFERENCE PORT CENTER CONDUCTOR.
3360 Ywt=Yot+Ot/2      ILOWER EDGE OF THE COUPLED SLOT.
3370 Yxt=Yot+Kt/2      IUPPER EDGE OF THE DIFFERENCE MICROSTRIP.
3380 Yyt=Yot-Kt/2      ILOWER EDGE OF THE DIFFERENCE MICROSTRIP.
3390 Yzt=Yot-Bt/2      ILOWER EDGE OF DIFFERENCE PORT CENTER CONDUCTOR.
3400 Yaet=Yot-Ot/2-It-Bat IEND OF SUB PORT MICROSTRIP.
3410 Yabt=-Yit         IEND OF PORT 2 MICROSTRIP.
3420 Yact=-Ybt         ITIP OF LOWER INPUT NOTCH (USED TO DRAW MICROSTRIP).
3430 Yadt=-Yat         IBOTTOM OF LOWER INPUT PORT.
3440 Yaet=Yadt-Space   ITOP OF THE RULER.
3450 Yaft=Yaet-2*Sixteenth ILOWER TIP OF A RULER MARK.
3460 Yagt=Yaft-Sixteenth ILOWER TIP OF A RULER MARK.
3470 Yajt=Yagt-Sixteenth ILOWER TIP OF A RULER MARK.
3480 Yait=Yaht-Sixteenth ILOWER TIP OF A RULER MARK.
3490 Yajt=Yait-Sixteenth ILOWER TIP OF A RULER MARK.
3500 Yakt=Yaet-.57*In   IFIRST LINE OF WORDS UNDER THE RULER.
3510 Yalt=Yaet-.72*In  ISECOND LINE OF WORDS UNDER THE RULER.
3520 I
3530 I
3540 Yoh=Yot           ICENTER OF HORN.
3550 Yah=Yot+Jt/2      ITOP OF HORN SLOT.
3560 Ybh=Yot+Eh        IEND OF HORN OPENING.
3570 IF Drawing$="MOHO" THEN 3600
3580 Ych=Yjt          IPLACE WHERE HORN JOINS THE FIXTURE.
3590 GOTO 3610
3600 Ych=Yot+Qt+Jt/2   ITHIS KEEPS THE COPPER Lambda/2 ABOVE THE SLOT.
3610 Ydh=Ybh+Dh        ITOP OF HORN.
3620 I
3630 I
3640 Ydmh=Ydt+Lambdad/2 IUSED TO MOVE X31t UP TO X31mh.
3650 Yemh=Yet-Lambdad/2 IUSED TO MOVE X28t DOWN TO X28mh.
3660 Yfmh=Yft+TAN(22.5)*(Lambdad/2) IUSED TO MOVE X32t UP TO X32mh.
3670 Ygmh=Ygt-TAN(22.5)*(Lambdad/2) IUSED TO MOVE X27t DOWN TO X26mh.
3680 Ykmh=Ykt+TAN(22.5)*(Lambdad/2) IUSED TO MOVE X33t UP TO X33mh.
3690 Ylmh=Ylt-TAN(22.5)*(Lambdad/2) IUSED TO MOVE X26t DOWN TO X26mh.
3700 Yqmh=Yqt+Lambdad/2 IUSED TO MOVE X34t UP TO X34mh.
3710 Yrmh=Yrt-Lambdad/2 IUSED TO MOVE X25t DOWN TO X25mh.
3720 I STEP FIVE: CALCULATION OF CORRECTIONS THAT WILL BE USED TO REMOVE
3730 I ERRORS FROM THE DRAWING THAT ARE CAUSED BY THE PLOTTER.
3740 I
3750 I THERE IS A SLIGHT BIT OF LOSENESS IN THE PEN CABLE ON THE HP 9872C
3760 I PLOTTER. THE AMOUNT OF ERROR THAT THIS INDUCES IS WITHIN THE PLOTTERS
3770 I SPECIFICATIONS AND DOES NOT CAUSE ANY PROBLEM IN MOST PLOTTER
3780 I APPLICATIONS. HOWEVER, DUE TO THE EXTREMELY SMALL DIMENSIONS IN THE
3790 I AREA NEAR THE COUPLED SLOTS, THESE ERRORS MUST BE ACCOUNTED FOR IN
3800 I THIS PROGRAM. THESE CORRECTIONS CAME FROM EMPIRICAL TESTING AND
3810 I WILL HAVE TO BE ADJUSTED TO MATCH THE PARTICULAR PLOTTER THAT IS
3820 I BEING USED. THE In/Hm SCALING IS INTENTIONALLY OMITTED TO KEEP THE
3830 I THE CORRECTIONS TO THE SCALE OF THE ACTUAL DRAWING AND PEN.
3840 Plottercorrect1=.07
3850 Plottercorrect2=0
3860 Plottercorrect3=0
3870 Plottercorrect4=0
3880 Pen=.52           ITHIS IS THE PEN THICKNESS, AND IT IS CORRECTED
3890 I FOR AUTOMATICALLY IN THE DRAWING.
3900 I
3910 I
3920 I STEP SIX: ENTER TWO MAJOR LOOPS THAT MAKE THE DESIRED DRAWING:
3930 I
3940 I THE FIRST LOOP (THE "Fill" LOOP) IS USED TO FILL IN THE BLACK
3950 I PORTIONS OF THE DRAWING. THIS IS DONE BY MOVING EACH POINT OF THE
3960 I FIGURE IN 60% OF THE PEN THICKNESS, AND THEN DRAWING IT OVER AGAIN.

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3970 |
3980 | THE SECOND LOOP (THE "Im" LOOP) IS USED TO DRAW THE FIN-LINE PATTERN.
3990 | THE BOTTOM HALF IS ESSENTIALLY A MIRROR IMAGE OF THE TOP. THEREFORE,
4000 | ONLY THE TOP HALF IS DEFINED. THE BOTTOM HALF IS DRAWN BY MULTIPLYING
4010 | THE "Y" COORDINATES BY MINUS ONE. ANY NON-SYMETRIC AREAS (SUCH AS
4020 | THE SUM PORT) ARE TAKEN CARE OF WITH "IF" STATEMENTS, THAT CHECK TO
4030 | SEE IF THE TOP OR BOTTOM HALF IS BEING DRAWN.
4040 |
4050 |
4060 | FOR Fill=1 TO 1 STEP 2 ISTART OF THE "Fill" LOOP.
4070 | FOR Image=0 TO 2 STEP 2 ISTART OF THE "Im" LOOP.
4080 | Im=1-Image IIm=1 DRAWS THE TOP, AND Im=-1 DRAWS THE
4090 | BOTTOM OF THE SLOTLINE SIDE.
4100 | IF Fill=3 THEN Segmentsize=Segmentsize*3
4110 | IF Fill>1 THEN GOTO 4180 ISKIPS TO THE "Fill" ROUTINE.
4120 | IF Im=1 THEN Penn=Pen*Fill !PLOTTER CORRECTION FOR THE
4130 | ! TOP HALF OF SLOTLINE SIDE.
4140 | IF Im=-1 THEN Penn=Pen*Fill+Plottercorrect1 !PLOTTER CORRECTION FOR THE
4150 | ! BOTTOM HALF OF THE SLOTLINE
4160 | ! SIDE.
4170 | GOTO 4230 ISKIPS "Fill" ROUTINE ON FIRST PASS.
4180 | IF Im=1 THEN Penn=Pen*Fill*.60 !"Fill" ROUTINE. MOVES PEN IN 60% OF
4190 | ! IT'S WIDTH AND THEN DRAWS THE
4200 | ! FIGURE AGAIN.
4210 |
4220 |
4230 | STEP SEVEN: CALCULATION OF CORRECTIONS THAT WILL BE USED TO REMOVE
4240 | ERRORS FROM THE DRAWING THAT ARE CAUSED BY THE PEN.
4250 |
4260 | THE FOLLOWING CALCULATIONS ARE USED TO ELIMINATE ANY INACCURACY IN
4270 | THE DRAWING DUE TO THE WIDTH OF THE PEN THAT IS BEING USED.
4280 | THESE ADJUSTMENTS WILL AUTOMATICALLY MOVE THE PEN THE APPROPRIATE
4290 | AMOUNT AND DIRECTION TO ACCOUNT FOR HALF OF THE THICKNESS OF THE PEN.
4300 |
4310 | Angle1=(180-ATN((Bt-Kt)/(2*Lt)))/2 !HALF OF THE ANGLE FORMED BY
4320 | ! POINTS 102,103 AND 104.
4330 | Penoffset1=Penn/(2*TAN(Angle1)) !CORRECTS POINTS 102, 103, 106 AND
4340 | ! 107 IN THE "X" DIRECTION AND
4350 | ! POINTS 111, 112, 115 AND 116 IN
4360 | ! "Y" DIRECTION.
4370 |
4380 | Angle2=ATN(At/(2*Lt)) !HALF OF THE ANGLE FORMED BY
4390 | ! POINTS 2,1 AND THE IMAGE OF 1.
4400 | Penoffset2=Penn/(2*SIN(Angle2)) !CORRECTS POINT 1 IN THE "X"
4410 | ! DIRECTION AND POINT 5 IN THE
4420 | ! "Y" DIRECTION.
4430 |
4440 | Angle3=(180-ATN((Bt-Kt)/(2*(Lt+Ct)))/2 !HALF OF THE ANGLE FORMED BY
4450 | ! POINTS 118,119 AND 120.
4460 | Penoffset3=Penn/(2*TAN(Angle3)) !CORRECTS POINTS 119,122,125 AND
4470 | ! 128 IN THE "Y" DIRECTION.
4480 |
4490 | Angle3a=(90-(180-2*Angle3))/2 ! HALF OF THE ANGLE FORMED BY
4500 | ! POINTS 117,118 AND 119.
4510 | Penoffset3a=Penn/(2*TAN(Angle3a)) !CORRECTS POINTS 117,118, 123 AND
4520 | ! 124 IN THE "X" DIRECTION.
4530 |
4540 | Angle4=ATN(At/(2*(Lt+Ct))) ! HALF OF THE ANGLE FORMED BY
4550 | ! POINTS 11, 12 AND 13.
4560 | Penoffset4=Penn/(2*SIN(Angle4)) !CORRECTS POINT 12 IN THE "Y"
4570 | ! DIRECTION.
4580 |
4590 | Angle5=(180-ATN(2*Lt/At))/2 !HALF OF THE ANGLE FORMED BY
4600 | ! POINTS 1,2 AND 3.
4610 | Penoffset5=Penn/(2*TAN(Angle5)) !CORRECTS POINT 2 IN THE "Y"
4620 | ! DIRECTION AND POINTS 4 AND 5

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4630                                     I IN THE "X" DIRECTION.
4640 I
4650 Angle6=(180-ATH(2*(Lt+Ct)/At))/2      I HALF OF THE ANGLE FORMED BY POINTS
4660                                     I 10,11 AND 12.
4670 Penoffset6=Penn/(2*TAN(Angle6))      ICORRECTS POINTS 11 AND 13 IN THE
4680                                     I "X" DIRECTION.
4690 I
4700 Penoffset7=Pen/(2*TAN(67.5))          ICORRECTS POINTS 23, 24, 25, 28
4710                                     I 31, 34, 35 AND 36 IN THE "X"
4720                                     I DIRECTION, AND POINTS 26, 27, 32
4730                                     I AND 33 IN THE "Y" DIRECTION.
4740 Penoffset7a=Penn/(2*COS(45))          ICORRECTS POINT 18 IN THE "X"
4750                                     I DIRECTION.
4760 I
4770 Angle8=(180-ATH((Mt/2+Ht-Ot/2-It)/Ht))/2 I HALF OF THE ANGLE FORMED BY
4780                                     I POINTS 37, 38 AND 39.
4790 Penoffset8=Penn/(2*TAN(Angle8))      ICORRECTS POINTS 37 AND 38 IN
4800                                     I THE "X" DIRECTION.
4810 I
4820 Angle9=(180-ATH((Mt/2-Ot/2)/(Ht+Bst-Bdt)))/2 I HALF OF THE ANGLE FORMED
4830                                     I BY POINTS 21, 22 AND 23.
4840 Penoffset9=Penn/(2*TAN(Angle9))      ICORRECTS POINTS 21 AND 22 IN
4850                                     I THE "X" DIRECTION.
4860 I
4870 Angleh1=45-Angleh IUSED TO DETERMINE OFFSETS AT END OF HORN.
4880 Angleh2=(180-Angleh)/2 IUSED TO DETERMINE OFFSETS AT MOUTH OF HORN.
4890 I
4900 Penoffseth1=SQR(2)*Penn/2*SIN(Angleh1) ICORRECTS 2h IN "X" DIRECTION AND
4910                                     I 3h IN "Y" DIRECTION.
4920 Penoffseth2=SQR(2)*Penn/2*COS(Angleh1) ICORRECTS 3h IN "X" DIRECTION AND
4930                                     I 2h IN THE "Y" DIRECTION.
4940 Penoffseth3=Penn/2/TAN(Angleh2)      ICORRECTS 1h AND 4h IN THE "X"
4950                                     I DIRECTION.
4960 I
4970 I
4980 I STEP EIGHT: DEFINE ALL NUMBERED POINTS ON THE DRAWING IN TERMS OF THE
4990 I "X" AND "Y" REFERENCE PLANES LISTED ABOVE.
5000 I
5010 I THE PEN OFFSET CALCULATIONS ARE ENTERED HERE. THIS KEEPS THE
5020 I REFERENCE PLANES FREE OF PEN CORRECTIONS.
5030 I
5040 I THE FOLLOWING POINTS DEFINE THE FIN-LINE SIDE.
5050 I
5060 X1t=Xct+Penoffset2
5070 X2t=Xbt+Penn/2 ITHIS IS FOR THE FIN-LINE SIDE OF POINT 2.
5080 X2at=Xbt-Penn/2 ITHIS IS FOR THE DIELECTRIC TAB SIDE OF POINT 2.
5090 X3t=Xbt+Penn/2
5100 X4t=Xht-Penoffset5 ITHIS IS FOR THE FIN-LINE SIDE OF POINT 4.
5110 X4at=Xht-Penn/2 ITHIS IS FOR THE DIELECTRIC TAB SIDE OF POINT 4.
5120 X5t=Xot
5130 X6t=Xnt+Penoffset5 ITHIS IS FOR THE FIN-LINE SIDE OF POINT 6.
5140 X6at=Xnt+Penn/2 ITHIS IS FOR THE DIELECTRIC TAB SIDE OF POINT 6.
5150 X7t=Xvt+Penn/2
5160 X8t=Xvt+Penn/2
5170 X9t=Xvt+Penn/2
5180 X10t=Xyt+Penoffset7
5190 X11t=Xadt-Penoffset6
5200 X12t=Xagt
5210 X13t=Xajt+Penoffset6
5220 X14t=Xalt-Penn/2
5230 X15t=Xalt-Penn/2
5240 X16t=Xalt-Penn/2
5250 X17t=Xut-Penoffset7
5260 X18t=Xit-Penoffset7a
5270 X19t=Xdt I THE PEN OFFSET FOR THE ARC IS DONE WHILE MAKING THE DRAWING.
5280 X20t=Xdt

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5290 X21t=Xft-Penoffset9
5300 X22t=Xjt-Penoffset9
5310 X23t=Xqt+Penoffset7
5320 X24t=Xst+Penoffset7
5330 X25t=Xxt+Penoffset7
5340 X26t=Xaat+Penn/2
5350 X27t=Xaat+Penn/2
5360 X28t=Xact+Penoffset7
5370 X29t=Xakt+Penn/2
5380 X30t=Xakt+Penn/2
5390 X31t=Xabt-Penoffset7
5400 X32t=Xzt-Penn/2
5410 X33t=Xzt-Penn/2
5420 X34t=Xwt-Penoffset7
5430 X35t=Xrt-Penoffset7
5440 X36t=Xpt-Penoffset7
5450 X37t=Xkt+Penoffset8
5460 X38t=Xgt+Penoffset8
5470 X39t=Xdt
5480 X40t=Xat-Penn/2
5490 X41t=Xat-Penn/2
5500 X42t=Xht-Penn/2
5510 X43t=Xnt+Penn/2
5520 !
5530 !
5540 ! THE FOLLOWING POINTS DEFINE THE MICROSTRIP SIDE.
5550 !
5560 !
5570 X101t=Xat+Penn/2
5580 X102t=Xbt-Penoffset1
5590 X103t=Xct-Penoffset1
5600 X104t=Xet-Penn/2
5610 X105t=Xet-Penn/2
5620 X106t=Xct-Penoffset1
5630 X107t=Xbt-Penoffset1
5640 X108t=Xat+Penn/2
5650 X109t=Xit+Penn/2
5660 X110t=Xmt-Penn/2
5670 X111t=Xmt-Penn/2
5680 X112t=Xlt-Penn/2
5690 X113t=Xlt-Penn/2
5700 X114t=Xkt+Penn/2
5710 X115t=Xkt+Penn/2
5720 X116t=Xlt+Penn/2
5730 X117t=Xaet+Penoffset3a
5740 X118t=Xait-Penoffset3a
5750 X119t=Xaht-Penn/2
5760 X120t=Xaht-Penn/2
5770 X121t=Xaft+Penn/2
5780 X122t=Xaft+Penn/2
5790 X123t=Xait-Penoffset3a
5800 X124t=Xaet+Penoffset3a
5810 X125t=Xaft+Penn/2
5820 X126t=Xaft+Penn/2
5830 X127t=Xaht-Penn/2
5840 X128t=Xaht-Penn/2
5850 !
5860 ! THE FOLLOWING POINTS DEFINE THE HORN.
5870 X1h=Xdh+Penoffseth3.
5880 X2h=Xbh-Penoffseth1
5890 X3h=Xah-Penoffseth2
5900 X4h=Xch-Penoffseth3
5910 X5h=Xeh-Penn/2
5920 X6h=Xeh-Penn/2
5930 !
5940 ! THE FOLLOWING POINTS ARE USED TO MERGE THE MAGIC-TEE AND HORN INTO THE

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5950  I MONOPULSE SYSTEM.
5960  X25mh=Xxmh-Penoffset7
5970  X26mh=Xaamh-Penn/2
5980  X27mh=Xaamh-Penn/2
5990  X28mh=Xacmh-Penoffset7
6000  X31mh=Xabmh+Penoffset7
6010  X32mh=Xzmh+Penn/2
6020  X33mh=Xzmh+Penn/2
6030  X34mh=Xwmh+Penoffset7
6040  I
6050  I THE FOLLOWING POINTS ARE USED TO DRAW THE RULER, BULL'S EYES AND
6060  I COMMENTS.
6070  X150t=Xat          ILEFT SIDE OF THE RULER.
6080  Xbul1left=Xat+.25*In  ICENTER OF LEFT BULL'S EYE.
6090  Xbul1right=Xalt-.25*In ICENTER OF RIGHT BULL'S EYE.
6100  I
6110  I
6120  I THE FOLLOWING LINES DEFINE THE "Y" COORDINATES OF THE FIN-LINE SIDE.
6130  I
6140  Y1t=Yot
6150  Y2t=Ynt+Penoffset5
6160  Y2at=Ynt+Penn/2
6170  Y3t=Yjt-Penn/2
6180  Y4t=Yjt-Penn/2
6190  Y4at=Yjt+Penn/2
6200  Y5t=Ymt-Penoffset2
6210  Y6t=Yjt-Penn/2
6220  Y6at=Yjt+Penn/2
6230  Y7t=Yjt-Penn/2
6240  Y8t=Yct-Penn/2
6250  Y9t=Yat-Penn/2
6260  Y10t=Yat-Penn/2
6270  Y11t=Yat-Penn/2
6280  Y12t=Ybt-Penoffset4
6290  Y13t=Yat-Penn/2
6300  Y14t=Yat-Penn/2
6310  Y15t=Ytt+Penn/2
6320  Y16t=Yot
6330  Y17t=Ytt+Penn/2
6340  Y18t=Yot
6350  Y19t=Yot
6360  Y20t=Yst-Penn/2
6370  Y21t=Yst-Penn/2
6380  Y22t=Ywt-Penn/2
6390  Y23t=Ywt-Penn/2
6400  Y24t=Yrt-Penn/2
6410  Y25t=Yrt-Penn/2
6420  Y26t=Ylt-Penoffset7
6430  Y27t=Ygt-Penoffset7
6440  Y28t=Yet-Penn/2
6450  Y29t=Yet-Penn/2
6460  Y30t=Ydt+Penn/2
6470  Y31t=Ydt+Penn/2
6480  Y32t=Yft+Penoffset7
6490  Y33t=Ykt+Penoffset7
6500  Y34t=Yqt+Penn/2
6510  Y35t=Yqt+Penn/2
6520  Y36t=Yut+Penn/2
6530  Y37t=Yut+Penn/2
6540  Y38t=Ypt+Penn/2
6550  Y39t=Ypt+Penn/2
6560  Y40t=Yot
6570  Y41t=Ynt+Penn/2
6580  Y42t=Yht+Penn/2
6590  Y43t=Yht+Penn/2
6600  I

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6610 I
6620 I THE FOLLOWING POINTS DEFINE THE MICROSTRIP SIDE.
6630 Y101t=Yvt-Penn/2
6640 Y102t=Yvt-Penn/2
6650 Y103t=Yxt-Penn/2
6660 Y104t=Yxt-Penn/2
6670 Y105t=Yyt+Penn/2
6680 Y106t=Yyt+Penn/2
6690 Y107t=Yzt+Penn/2
6700 Y108t=Yzt+Penn/2
6710 Y109t=Yht-Penn/2
6720 Y110t=Yht-Penn/2
6730 Y111t=Yjt+Penoffset1
6740 Y112t=Ymt+Penoffset1
6750 Y113t=Yaat+Penn/2
6760 Y114t=Yaat+Penn/2
6770 Y115t=Ymt+Penoffset1
6780 Y116t=Yjt+Penoffset1
6790 Y117t=Yat-Penn/2
6800 Y118t=Yat-Penn/2
6810 Y119t=Ybt+Penoffset3
6820 Y120t=Yit+Penn/2
6830 Y121t=Yit+Penn/2
6840 Y122t=Ybt+Penoffset3
6850 Y123t=Yadt+Penn/2
6860 Y124t=Yadt+Penn/2
6870 Y125t=Yact-Penoffset3
6880 Y126t=Yabt+Penn/2
6890 Y127t=Yabt-Penn/2
6900 Y128t=Yact-Penoffset3
6910 I
6920 Y1h=Ych-Penn/2
6930 Y2h=Ydh-Penoffseth2
6940 Y3h=Ybh+Penoffseth1
6950 Y4h=Yah+Penn/2
6960 Y5h=Yah+Penn/2
6970 Y6h=Yot
6980 I
6990 I THE FOLLOWING POINTS ARE USED TO MERGE THE MAGIC-TEE AND THE HORN
7000 I INTO THE MONOPULSE SYSTEM.
7010 Y25mh=Yrmh+Penn/2
7020 Y26mh=Ylmh+Penoffset7
7030 Y27mh=Ygmh+Penoffset7
7040 Y28mh=Yemh+Penn/2
7050 Y31mh=Ydmh-Penn/2
7060 Y32mh=Yfmh-Penoffset7
7070 Y33mh=Ykmh-Penoffset7
7080 Y34mh=Yqmh-Penn/2
7090 I
7100 I THE FOLLOWING POINTS ARE USED TO DRAW THE BULL'S EYES.
7110 Ybulltop=Yat+2*Space
7120 Ybullbottom=-Ybulltop
7130 I
7140 I STEP NINE: MAKE THE DESIRED DRAWING.
7150 I
7160 I THE CENTER OF THE DRAWING IS X0,Y0. THIS IS THE POINT WHERE THE
7170 I CENTERS OF THE SUM AND DIFFERENCE MICROSTRIP LINES WOULD CROSS IF
7180 I EXTENDED. ALL OF THE DRAWINGS ARE REFERENCED FROM X0,Y0.
7190 I
7200 IF Drawing$="TEE" THEN 7600 ISKIP TO MAGIC-TEE SECTION.
7210 IF Drawing$="MONO" THEN 8700 ISKIP TO THE MONOPULSE SYSTEM SECTION.
7220 I
7230 I THIS SECTION DRAWS THE FIN-LINE SIDE OF A SINGLE FIN-LINE HORN.
7240 I
7250 IF Side$="M" THEN 7450 ISKIP TO MICROSTRIP SIDE.
7260 MOVE X1t,Y1t

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7270 DRAW X2t,Y2t*Im
7280 DRAW X3t,Y3t*Im
7290 IF Im=-1*Flip THEN 7330
7300 DRAW X4t,Y4t*Im
7310 DRAW X5t,Y5t*Im
7320 DRAW X6t,Y6t*Im
7330 GOSUB 10250 IDRAWS HORN.
7340 ! THE NEXT FEW LINES OUTLINE THE DIELECTRIC TABS TO MATCH THE FIXTURE.
7350 MOVE X40t,Y40t
7360 DRAW X41t,Y41t*Im
7370 DRAW X2at,Y2at*Im
7380 IF Im=-1*Flip THEN 7430
7390 MOVE X4at,Y4at*Im
7400 DRAW X42t,Y42t*Im
7410 DRAW X43t,Y43t*Im
7420 DRAW X6at,Y6at*Im
7430 NEXT Image
7440 GOTO 7570!SKIP MICROSTRIP SIDE.
7450 ! THIS SECTION DRAWS THE MICROSTRIP SIDE OF THE THE FIN-LINE HORN.
7460 MOVE X109t,Y109t
7470 DRAW X110t,Y110t
7480 DRAW X111t,Y111t
7490 DRAW X112t,Y112t
7500 Ybottomhms=Yot-Jt/2-Qwmicrostrip+Penn/2 !ONLY POINT UNIQUE TO HORN.
7510 DRAW X113t,Ybottomhms
7520 DRAW X114t,Ybottomhms
7530 DRAW X115t,Y115t
7540 DRAW X116t,Y116t
7550 DRAW X109t,Y109t
7560 !
7570 NEXT Fill
7580 GOTO 9380 ! SKIP TO THE RULER SECTION.
7590 !
7600 ! THIS SECTION DRAWS THE MAGIC-TEE.
7610 !
7620 IF Side$="M" THEN 8230 !THIS SKIPS TO MICRO-STRIP SIDE.
7630 !
7640 ! THIS SECTION DRAWS THE FIN-LINE SIDE OF THE FIN-LINE TEE.
7650 MOVE X1t,Y1t*Im
7660 DRAW X2t,Y2t*Im
7670 DRAW X3t,Y3t*Im
7680 IF Im=-1*Flip THEN GOTO 7720
7690 DRAW X4t,Y4t*Im
7700 DRAW X5t,Y5t*Im
7710 DRAW X6t,Y6t*Im
7720 DRAW X7t,Y7t*Im
7730 DRAW X8t,Y8t*Im
7740 DRAW X10t,Y10t*Im
7750 DRAW X11t,Y11t*Im
7760 DRAW X12t,Y12t*Im
7770 DRAW X13t,Y13t*Im
7780 DRAW X14t,Y14t*Im
7790 DRAW X16t,Y16t*Im
7800 MOVE X19t-Mt/2+Penn/2,Y19t
7810 FOR Angle=89 TO 180 STEP 2
7820 X=X19t-(Mt/2-Penn/2)*SIN(Angle)
7830 Y=(Y19t-(Mt/2-Penn/2)*COS(Angle))*Im
7840 DRAW X,Y
7850 NEXT Angle
7860 DRAW X21t,Y21t*Im
7870 IF Y22t>Yot THEN GOTO 7900 !KEEPS PEN BETWEEN COUPLED SLOTS.
7880 Y22t=Yot
7890 Y23t=Yot
7900 DRAW X22t,Y22t*Im
7910 DRAW X23t,Y23t*Im
7920 DRAW X24t,Y24t*Im

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7930 DRAW X25t,Y25t*Im
7940 DRAW X28t,Y28t*Im
7950 DRAW X29t,Y29t*Im
7960 DRAW X30t,Y30t*Im
7970 DRAW X31t,Y31t*Im
7980 DRAW X34t,Y34t*Im
7990 DRAW X35t,Y35t*Im
8000 DRAW X36t,Y36t*Im
8010 DRAW X37t,Y37t*Im
8020 DRAW X38t,Y38t*Im
8030 DRAW X39t,Y39t*Im
8040 FOR Angle=0 TO 91 STEP 1
8050 X=X19t-(Mt/2+Ht+Penn/2)*SIN(Angle)
8060 Y=(Y19t+(Mt/2+Ht+Penn/2)*COS(Angle))*Im
8070 DRAW X,Y
8080 NEXT Angle
8090 MOVE X40t,Y40t
8100 DRAW X41t,Y41t*Im
8110 DRAW X2at,Y2at*Im
8120 IF Im=-1*Flip THEN GOTO 8170
8130 MOVE X4at,Y4at*Im
8140 DRAW X42t,Y42t*Im
8150 DRAW X43t,Y43t*Im
8160 DRAW X6at,Y6at*Im
8170 MOVE X1,Y1
8180 NEXT Image
8190 GOTO 8560      !FIN-LINE SIDE IS COMPLETE. THIS COMMAND SKIPS THE
8200                ! MICROSTRIP SIDE, AND CONTINUES ON WITH THE PROGRAM.
8210 !
8220 ! THE FOLLOWING SECTION DRAWS THE MICROSTRIP SIDE OF THE MAGIC-TEE.
8230 MOVE X101t,Y101t
8240 DRAW X102t,Y102t
8250 DRAW X103t,Y103t
8260 DRAW X104t,Y104t
8270 DRAW X105t,Y105t
8280 DRAW X106t,Y106t
8290 DRAW X107t,Y107t
8300 DRAW X108t,Y108t
8310 DRAW X101t,Y101t
8320 MOVE X109t,Y109t*Flip
8330 DRAW X110t,Y110t*Flip
8340 DRAW X111t,Y111t*Flip
8350 DRAW X112t,Y112t*Flip
8360 DRAW X113t,Y113t*Flip
8370 DRAW X114t,Y114t*Flip
8380 DRAW X115t,Y115t*Flip
8390 DRAW X116t,Y116t*Flip
8400 DRAW X109t,Y109t*Flip
8410 MOVE X117t,Y117t
8420 DRAW X118t,Y118t
8430 DRAW X119t,Y119t
8440 DRAW X120t,Y120t
8450 DRAW X121t,Y121t
8460 DRAW X122t,Y122t
8470 DRAW X117t,Y117t
8480 MOVE X123t,Y123t
8490 DRAW X124t,Y124t
8500 DRAW X125t,Y125t
8510 DRAW X126t,Y126t
8520 DRAW X127t,Y127t
8530 DRAW X128t,Y128t
8540 DRAW X123t,Y123t
8550 ! THIS SECTION IS COMMON TO BOTH THE FIN-LINE AND THE MICROSTRIP SIDES.
8560 ! THE NEXT FEW LINES PLACE THE NUMBER OF THE MAGIC TEE NEAR THE DEVICE.
8570 CSIZE .06*In,.5
8580 MOVE Xvt+Penn,Yct+.60*Tt+Penn

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8590 LABEL Title$ IDRAWS THE NAME OF THE TEE ON THE DEVICE.
8600 NEXT Fill
8610 GOTO 9380 IMAGIC-TEE IS DONE, SKIP TO THE RULER SECTION.
8620 I
8630 I THIS SECTION DRAWS THE FIN-LINE SIDE OF THE MONOPULSE SYSTEM.
8640 I
8650 IF Side$="M" THEN 9170 ISKIP TO MICROSTRIP SIDE.
8660 MOVE X1t,Y1t*Im
8670 DRAW X2t,Y2t*Im
8680 DRAW X3t,Y3t*Im
8690 IF Im=-1*Flip THEN 8730 IFlip CONTROLS THE LOCATION OF PORT-3.
8700 DRAW X4t,Y4t*Im
8710 DRAW X5t,Y5t*Im
8720 DRAW X6t,Y6t*Im
8730 DRAW X7t,Y7t*Im ITHIS IS THE UPPER LEFT EDGE OF THE FIXTURE.
8740 DRAW X34mh,Y34mh*Im ITHIS IS THE FIRST POINT IN THE MONOPULSE SYSTEM
8750 I PORTION.
8760 DRAW X31mh,Y31mh*Im
8770 Imm=Im IUSED TO DRAW HORN CORRECTLY.
8780 GOSUB 10250 IDRAW HALF OF THE HORN.
8790 DRAW X31t,Y31t*Im
8800 DRAW X34t,Y34t*Im
8810 DRAW X35t,Y35t*Im
8820 DRAW X36t,Y36t*Im
8830 DRAW X37t,Y37t*Im
8840 DRAW X38t,Y38t*Im
8850 DRAW X39t,Y39t*Im
8860 FOR Angle=0 TO 91 STEP 1 INEXT FIVE LINES DRAW THE LEFT QUARTER ARC.
8870 X=X19t-(Mt/2+Ht+Penn/2)*SIN(Angle)
8880 Y=Y19t+(Mt/2+Ht+Penn/2)*COS(Angle))*Im
8890 DRAW X,Y
8900 NEXT Angle
8910 MOVE X25mh,Yot IMOVE BACK TO CENTER OF THE MONOPULSE SYSTEM PORTION.
8920 DRAW X28mh,Y28mh*Im
8930 Imm=-1*Im IFLIPS Im IN THE HORN SUBROUTINE TO DRAW BOTTOM HALF OF HORN.
8940 GOSUB 10250 IDRAW BOTTOM HALF OF THE HORN
8950 DRAW X28t,Y28t*Im ITHIS IS THE MAGIC-TEE PORTION AGAIN.
8960 DRAW X25t,Y25t*Im
8970 DRAW X24t,Y24t*Im
8980 DRAW X23t,Y23t*Im
8990 DRAW X22t,Y22t*Im
9000 DRAW X21t,Y21t*Im
9010 DRAW X20t,Y20t*Im
9020 FOR Angle=0 TO 91 STEP 1
9030 X=X19t-(Mt/2-Penn/2)*SIN(Angle)
9040 Y=(Y19t+(Mt/2-Penn/2)*COS(Angle))*Im
9050 DRAW X,Y
9060 NEXT Angle
9070 MOVE X40t,Y40t
9080 DRAW X41t,Y41t*Im
9090 DRAW X2at,Y2at*Im
9100 IF Im=-1*Flip THEN 9150
9110 MOVE X4at,Y4at*Im
9120 DRAW X42t,Y42t*Im
9130 DRAW X43t,Y43t*Im
9140 DRAW X6at,Y6at*Im
9150 NEXT Image
9160 GOTO 9360ISKIP THE MICROSTRIP SIDE.
9170 I THIS SECTION DRAWS THE MICROSTRIP SIDE OF THE MONOPULSE SYSTEM.
9180 MOVE X101t,Y101t
9190 DRAW X102t,Y102t
9200 DRAW X103t,Y103t
9210 DRAW X104t,Y104t
9220 DRAW X105t,Y105t
9230 DRAW X106t,Y106t
9240 DRAW X107t,Y107t

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9250 DRAW X100t,Y100t
9260 DRAW X101t,Y101t
9270 MOVE X109t,Y109t
9280 DRAW X110t,Y110t
9290 DRAW X111t,Y111t
9300 DRAW X112t,Y112t
9310 DRAW X113t,Y113t
9320 DRAW X114t,Y114t
9330 DRAW X115t,Y115t
9340 DRAW X116t,Y116t
9350 DRAW X109t,Y109t
9360 NEXT F111
9370 I
9380 I THIS SECTION DRAWS THE RULER AND COMMENTS.
9390 I
9400 IF Ruler$="N" THEN 10200
9410 I THE NEXT PORTION OF THE PROGRAM DRAWS THE NUMBERS AND COMMENTS BELOW
9420 I THE RULER.
9430 LINE TYPE 1 ITHIS RETURNIS THE PLOTTER TO A NORMAL HIGH SPEED LINE.
9440 Penn=Pen
9450 FOR I=1 TO 3*Scale STEP 1
9460 Penn=.8*Pen+Penn
9470 CSIZE .135*In,.35 I(HEIGHT OF LETTERS),(WIDTH/HEIGHT RATIO)
9480 MOVE X150t+.85*In+Penn,Yajt-Penn
9490 LABEL "1"
9500 MOVE X150t+1.85*In+Penn,Yajt-Penn
9510 LABEL "2"
9520 MOVE X150t+2.85*In+Penn,Yajt-Penn
9530 LABEL "3"
9540 IF I>Scale THEN GOTO 9800
9550 MOVE X150t+Penn,Yakt+Penn
9560 CSIZE .08*In,.48 I(HEIGHT OF LETTERS),(WIDTH/HEIGHT RATIO)
9570 LABEL "WHEN REDUCED TO 1:1 SCALE, THIS"
9580 MOVE X150t+Penn,Yalt+Penn
9590 LABEL "RULER WILL BE EXACTLY IN INCHES."
9600 I
9610 I THE FOLLOWING LINES DRAW THE COMMENTS BETWEEN THE BULL'S EYES.
9620 MOVE Xbullleft+.2*In+Penn,Ybulltop+Penn
9630 LABEL "MAGIC TEE ";Title$;" by LCDR ROWLEY"
9640 I
9650 I THE FOLLOWING LINES DRAW THE BULL'S EYES.
9660 MOVE Xbullleft+Penn,Ybulltop+.15*In+Penn
9670 DRAW Xbullleft+Penn,Ybulltop-.05*In+Penn
9680 MOVE Xbullleft-.1*In+Penn,Ybulltop+Penn+.05*In
9690 DRAW Xbullleft+.1*In+Penn,Ybulltop+Penn+.05*In
9700 FOR Angle=0 TO 360 STEP 5
9710 DRAW .1*In*COS(Angle)+Xbullleft+Penn,.1*In*SIN(Angle)+Ybulltop+.05*In+Penn
9720 NEXT Angle
9730 MOVE Xbullright+Penn,Ybulltop+.15*In+Penn
9740 DRAW Xbullright+Penn,Ybulltop-.05*In+Penn
9750 MOVE Xbullright-.1*In+Penn,Ybulltop+Penn+.05*In
9760 DRAW Xbullright+.1*In+Penn,Ybulltop+Penn+.05*In
9770 FOR Ang=0 TO 360 STEP 5
9780 DRAW .1*In*COS(Ang)+Xbullright+Penn,.1*In*SIN(Ang)+Ybulltop+.05*In+Penn
9790 NEXT Ang
9800 NEXT I
9810 I THE NEXT SEGMENT OF THE PROGRAM DRAWS THE RULER.
9820 J=1
9830 Penn=Pen
9840 FOR I=0 TO 6 STEP 1
9850 J=J+1
9860 X150t=Xat+I*(.5*In)
9870 MOVE X150t+Penn,Yaet I TOP OF THE RULER.
9880 I THE RULER IS DRAWN IN SIX HALF INCH SEGMENTS. THE ODD SEGMENTS START
9890 I WITH A LONG INCH MARK, WHILE THE EVEN SEGMENTS START WITH A SHORTER
9900 I HALF INCH MARK. THE NEXT SEVEN LINES CONSTRUCT THE FIRST MARK IN EACH

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9910 1 HALF INCH SEGMENT.
9920 IF I=1 THEN GOTO 9980      !SKIPS TO THE HALF INCH MARK LENGTH.
9930 IF I=3 THEN GOTO 9980      !SKIPS TO THE HALF INCH MARK LENGTH.
9940 IF I=5 THEN GOTO 9980      !SKIPS TO THE HALF INCH MARK LENGTH.
9950 DRAW X150t+Penn,Yajt      !THIS IS THE INCH MARK (LONGEST LINE).
9960 IF I=6 THEN GOTO 10150     !THIS TERMINATES THE RULER AFTER THREE INCHES.
9970 GOTO 10000                 !THIS SKIPS THE HALF INCH MARK LENGTH.
9980 DRAW X150t+Penn,Yait      !THIS IS THE HALF INCH MARK LENGTH.
9990 1 THE NEXT 14 LINES DRAWS EACH HALF INCH SEGMENT OF THE RULER.
10000 MOVE X150t+Penn+Sixteenth,Yaet
10010 DRAW X150t+Penn+Sixteenth,Yaft
10020 MOVE X150t+Penn+2*Sixteenth,Yaet
10030 DRAW X150t+Penn+2*Sixteenth,Yagt
10040 MOVE X150t+Penn+3*Sixteenth,Yaet
10050 DRAW X150t+Penn+3*Sixteenth,Yaft
10060 MOVE X150t+Penn+4*Sixteenth,Yaet
10070 DRAW X150t+Penn+4*Sixteenth,Yaht
10080 MOVE X150t+Penn+5*Sixteenth,Yaet
10090 DRAW X150t+Penn+5*Sixteenth,Yaft
10100 MOVE X150t+Penn+6*Sixteenth,Yaet
10110 DRAW X150t+Penn+6*Sixteenth,Yagt
10120 MOVE X150t+Penn+7*Sixteenth,Yaet
10130 DRAW X150t+Penn+7*Sixteenth,Yaft
10140 NEXT I
10150 IF J>8*Scale THEN GOTO 10200 !THIS TERMINATES THE PROGRAM WHEN LINES ARE
10160                                ! ARE THICK ENOUGH.
10170 Penn=Penn+Pen              ! THIS SHIFTS THE RULER SLIGHTLY AND REDRAWS
10180                                ! IT. THIS MAKES THE LINES THICK ENOUGH.
10190 GOTO 9840                  ! THIS CONTINUES THE LOOP.
10200 PEN 0                      ! THE PEN IS PUT BACK IN THE HOLDER.
10210 MOVE 5000,500             ! THE PEN DRIVE ARM IS MOVED ASIDE.
10220 STOP
10230 1
10240 1 STEP TEN: HORN SUBROUTINE.
10250 1 THE FOLLOWING SUBROUTINE DRANS HALF OF THE HORN AT A TIME.
10260 IF Drawing$="HORN" THEN 10320 !SKIP OFFSET FOR SINGLE HORN.
10270 Xoff=Xact-Xvt+Lambdad      !MOVES HORN OPENING ONE WAVELENGTH LEFT OF THE
10280                                ! LAST SLOT BEND (MONOHORN ONLY).
10290 Yoff=(Yt+Jt/2)*Im         ! MOVES HORN OPENING UP/DOWN TO MATCH SLOTS IN
10300                                ! THE MONOPULSE SYSTEM.
10310 GOTO 10350                 !SKIP TO DRAWING ROUTINE.
10320 Imm=Im                     !NEEDED FOR SINGLE HORN ONLY.
10330 Xoff=0                     !INSURES OFFSETS ARE ZERO FOR SINGLE HORN.
10340 Yoff=0
10350 DRAW X1h+Xoff,Y1h+Imm+Yoff
10360 DRAW X2h+Xoff,Y2h+Imm+Yoff
10370 DRAW X3h+Xoff,Y3h+Imm+Yoff
10380 DRAW X4h+Xoff,Y4h+Imm+Yoff
10390 IF Drawing$="MONO" THEN 10420 !POINTS 5&6 ARE FOR THE SINGLE HORN ONLY.
10400 DRAW X5h+Xoff,Y5h+Im+Yoff
10410 DRAW X6h+Xoff,Y6h+Im+Yoff
10420 1 THE NEXT PORTION DRAWS THE DOTTED LINE OF THE LENS ARC.
10430 IF Fill>1 THEN 7430
10440 LINE TYPE 4,.5*Scale      !DOTTED LINE.
10450 FOR Beta=0 TO Angleh STEP 1 !Beta(MAX)=Angleh.
10460 1 THE FOLLOWING LINES ARE THE EQUATION THAT DEFINES A PARALLEL
10470 1 PHASE FRONT LENS.
10480 Aarc=1-COS(Beta)
10490 Barc=1-COS(Angleh)
10500 Carc=1/SQR(Er)-COS(Beta)
10510 Darc=COS(Angleh)-1/SQR(Er)
10520 Earc=COS(Beta)*(1-SQR(Er))
10530 Brh=Bh*(Aarc+Barc*Carc/Darc)/Earc !THICKNESS OF LENS.
10540 Radh=Bh+Brh+Pen           !RADIUS FROM Xoh.Yoh TO LENS EDGE.
10550                                ! Bh IS RADIUS OF ARC WITHOUT LENS.
10560 Xarc=Xoh+Radh*COS(Beta)    !X POSITION OF ARC.

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10570 Yarc=Yoh+Radh*SIN(Beta)           IY POSITION OF ARC.
10580 IF Beta=0 THEN MOVE Xarc+Xoff,Yarc+Yoff IPOSITIONS PEN FOR ARC.
10590 DRAW Xarc+Xoff,Yarc+Imm+Yoff
10600 NEXT Beta
10610 IF Drawing$="H" THEN 10650 I FOLLOWING LINES ARE FOR MONOHORN ONLY.
10620 MOVE X4h+Xoff,Y4h+Imm+Yoff IRETURNS DRAWING TO PROPER POINT AFTER LENS IS
10630 I IS DRAWN.
10640 LINE TYPE Linenumber,Segmentsize IRETURNS LINE TYPE TO PREVIOUS SETTING.
10650 RETURN
10660 END

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APPENDIX B

FIGURES

FIN-LINE MAGIC-TEE NUMBER THREE

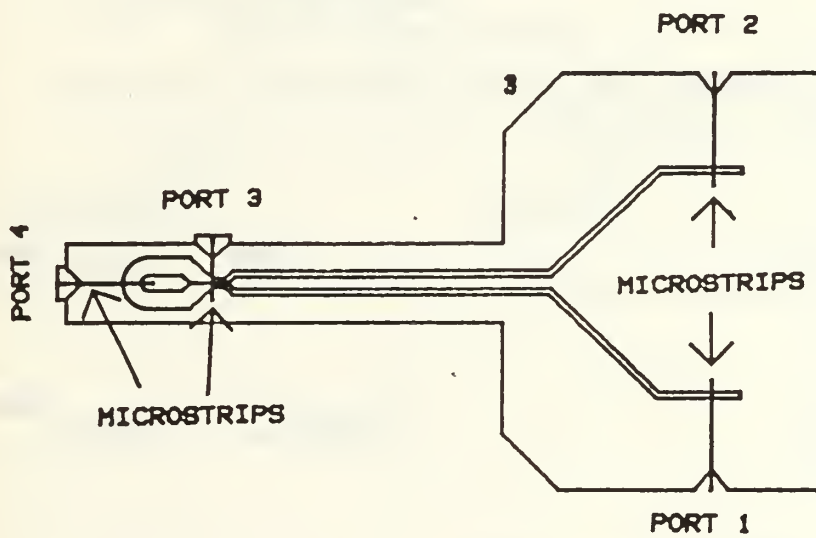


Figure 1 Fin-Line Magic-Tee.

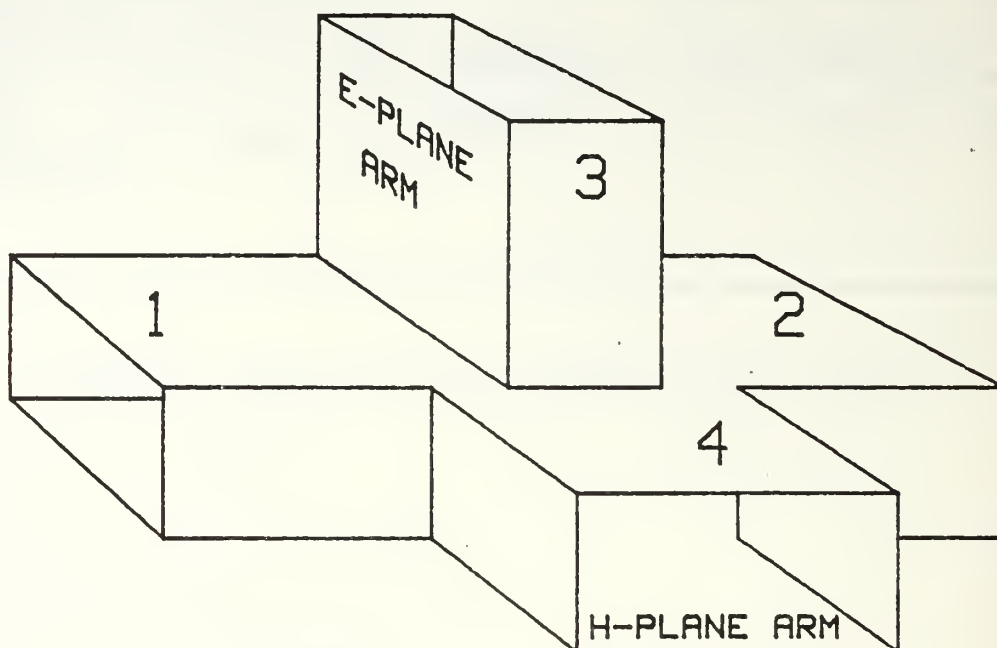


Figure 2 Waveguide Magic-Tee.

$$S = \begin{bmatrix} 0 & 0 & .707e^{j000} & .707e^{j000} \\ 0 & 0 & .707e^{-j180} & .707e^{j000} \\ .707e^{j000} & .707e^{-j180} & 0 & 0 \\ .707e^{j000} & .707e^{j000} & 0 & 0 \end{bmatrix}$$

Figure 3 Theoretical Magic-Tee Scattering Matrix.

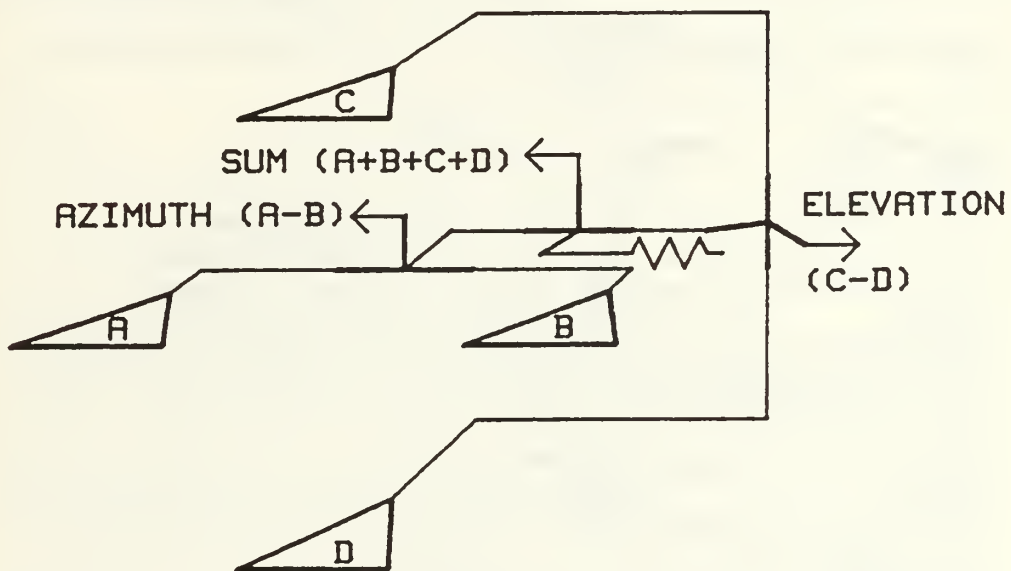
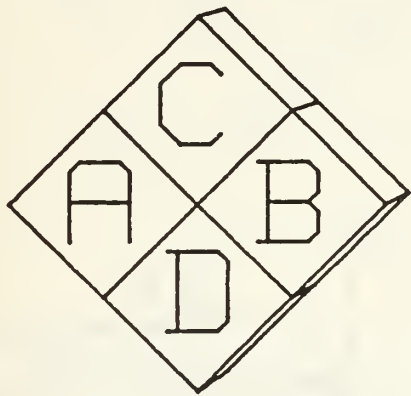


Figure 4 Diamond Monopulse Feed.

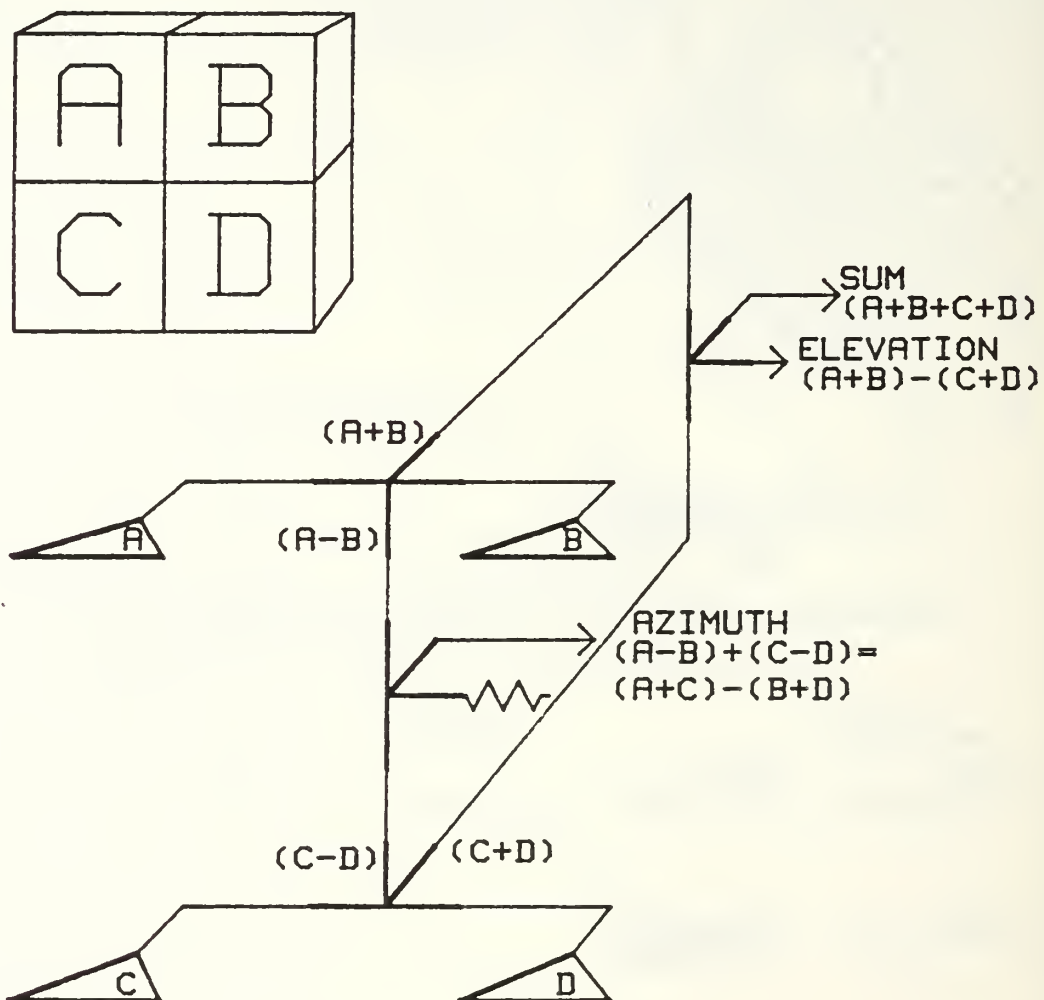
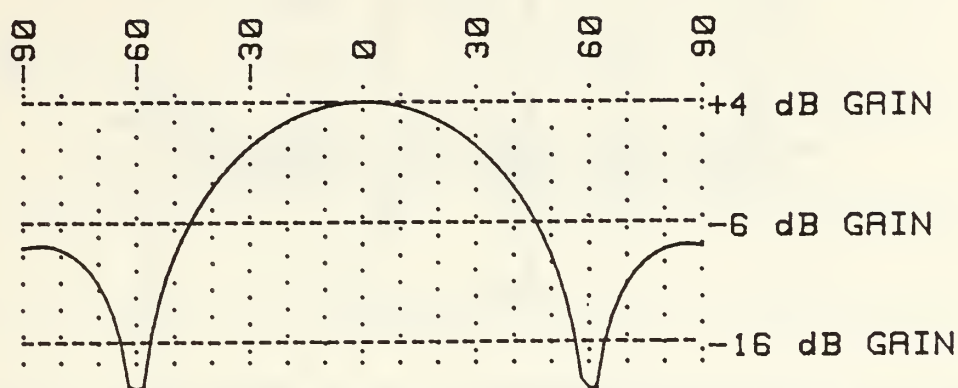
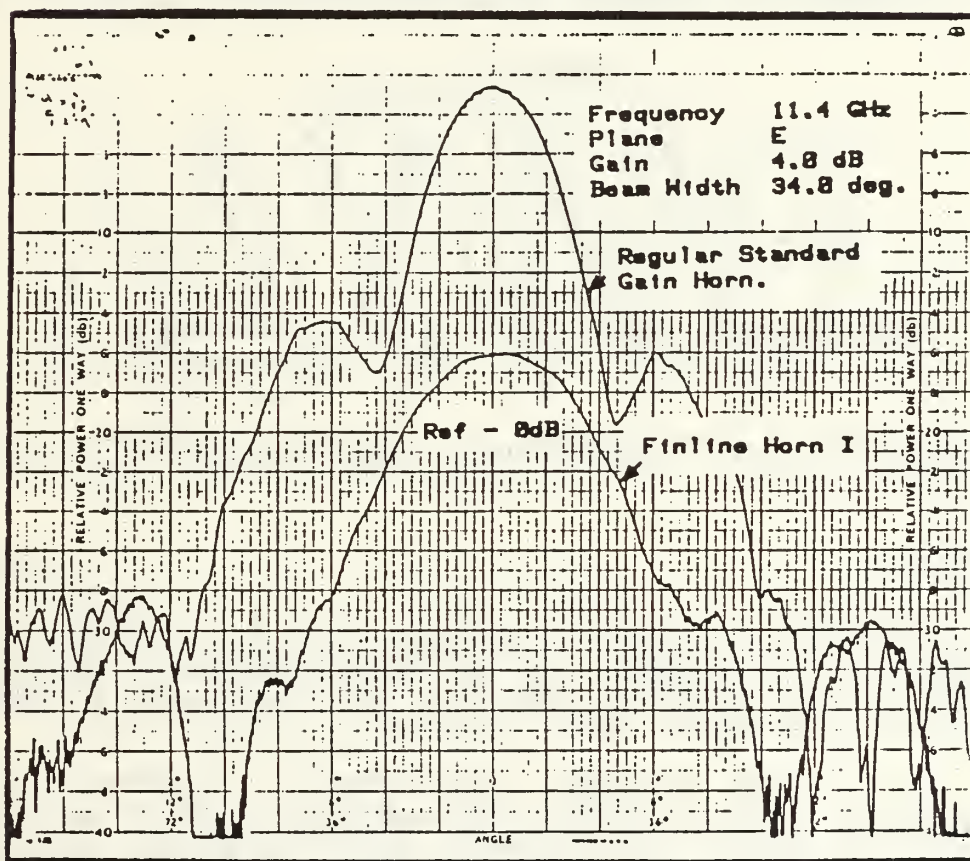


Figure 5 Square Monopulse Feed.

Degrees Left(-) and Right(+) of Boresight .

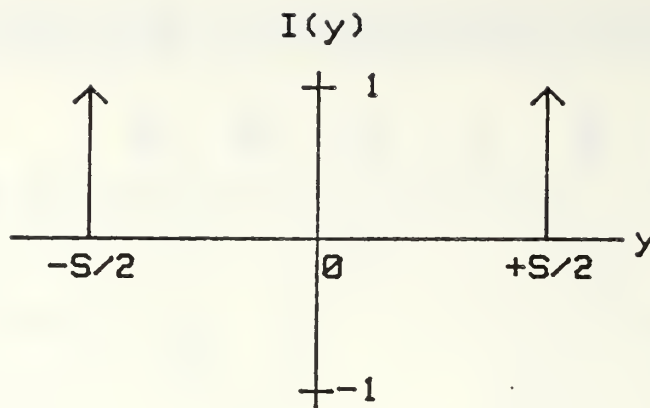


Computer Simulation of Actual
Element Pattern.

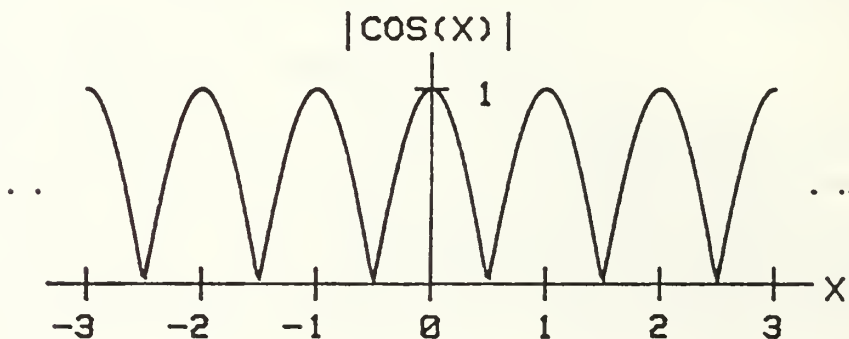


Actual Element Pattern at 11.4 GHZ.

Figure 6 Simulated and Actual Element Pattern.



Spacing between elements of a Monopulse Feed, showing the elements in phase with each other. Each element is represented by a delta function. The element pattern is accounted for later.

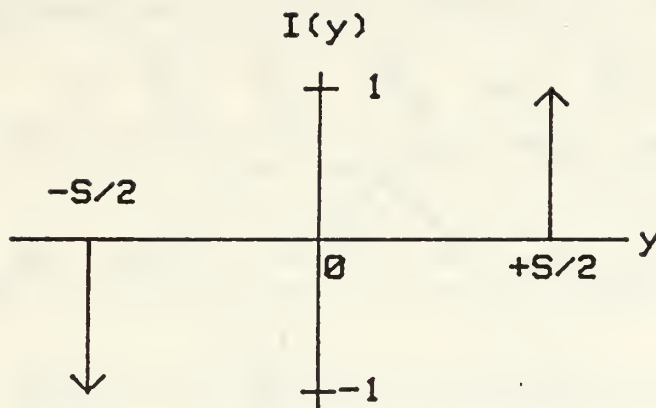


Fourier Transformed Sum Group pattern.

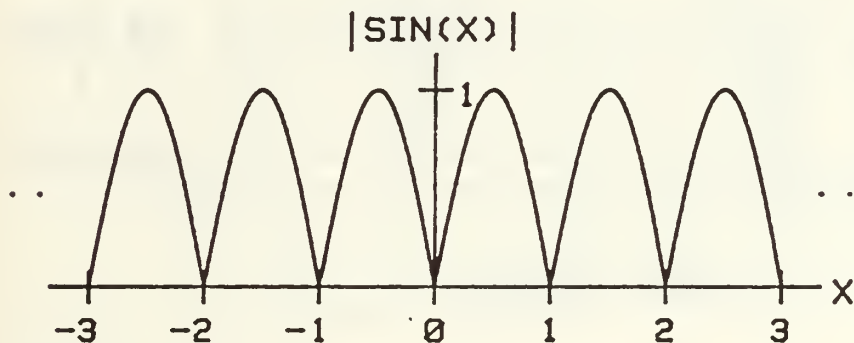
NOTES:

1. $X = \sin(\theta) * (S/\lambda)$; θ is the angle left(-), or right(+), of the antenna's boresight. 'S' is the spacing between the antenna elements.
2. At ± 90 degrees, $\sin(\theta)$ reaches it's maximum value of one. These two points are called the pattern's visible limits. They occur where $X = \pm (1) * (S/\lambda)$ on the transformed pattern.

Figure 7 Theoretical Sum Group Pattern.



Spacing between elements of a Monopulse Feed, showing the elements out of phase with each other. Each element is represented by a delta function. The element pattern is accounted for later.



Fourier Transformed Difference Group Pattern.

NOTES:

1. $X = \text{SIN}(\text{Theta}) * (S / \text{Lambda})$; Theta is the angle left(-), or right(+), of the antenna's bore sight. 'S' is the spacing between the antenna elements.
2. At ± 90 degrees, $\text{SIN}(\text{Theta})$ reaches it's maximum value of one. These two points are called the pattern's visible limits. They occur where $X = \pm (1) * (S / \text{Lambda})$ on the transformed pattern.

Figure 8 Theoretical Difference Group Pattern.

Degrees Left(-) and Right(+) of Boresight

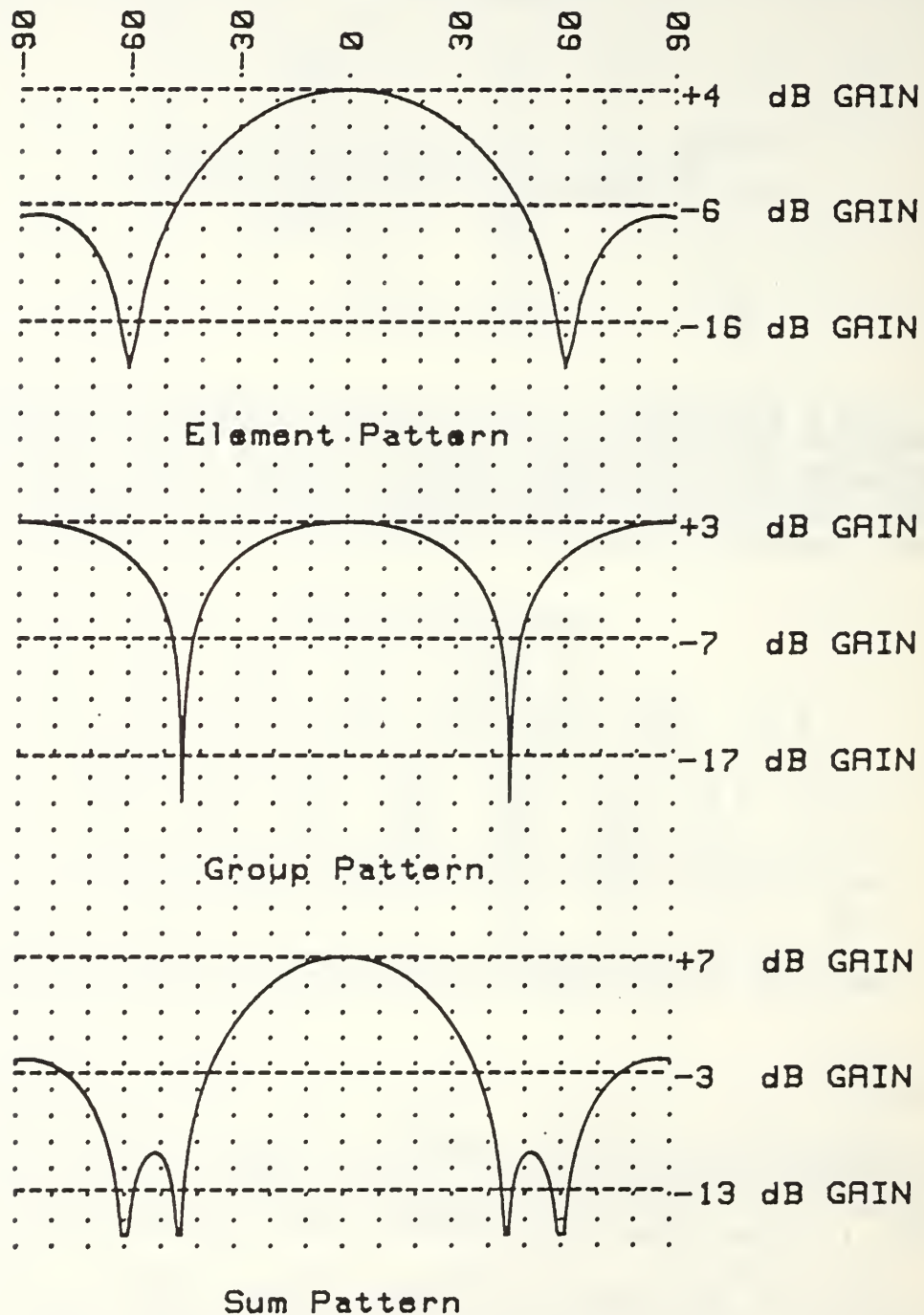


Figure 9 Theoretical Sum Pattern.

Degrees Left(-) and Right(+) of Boresight

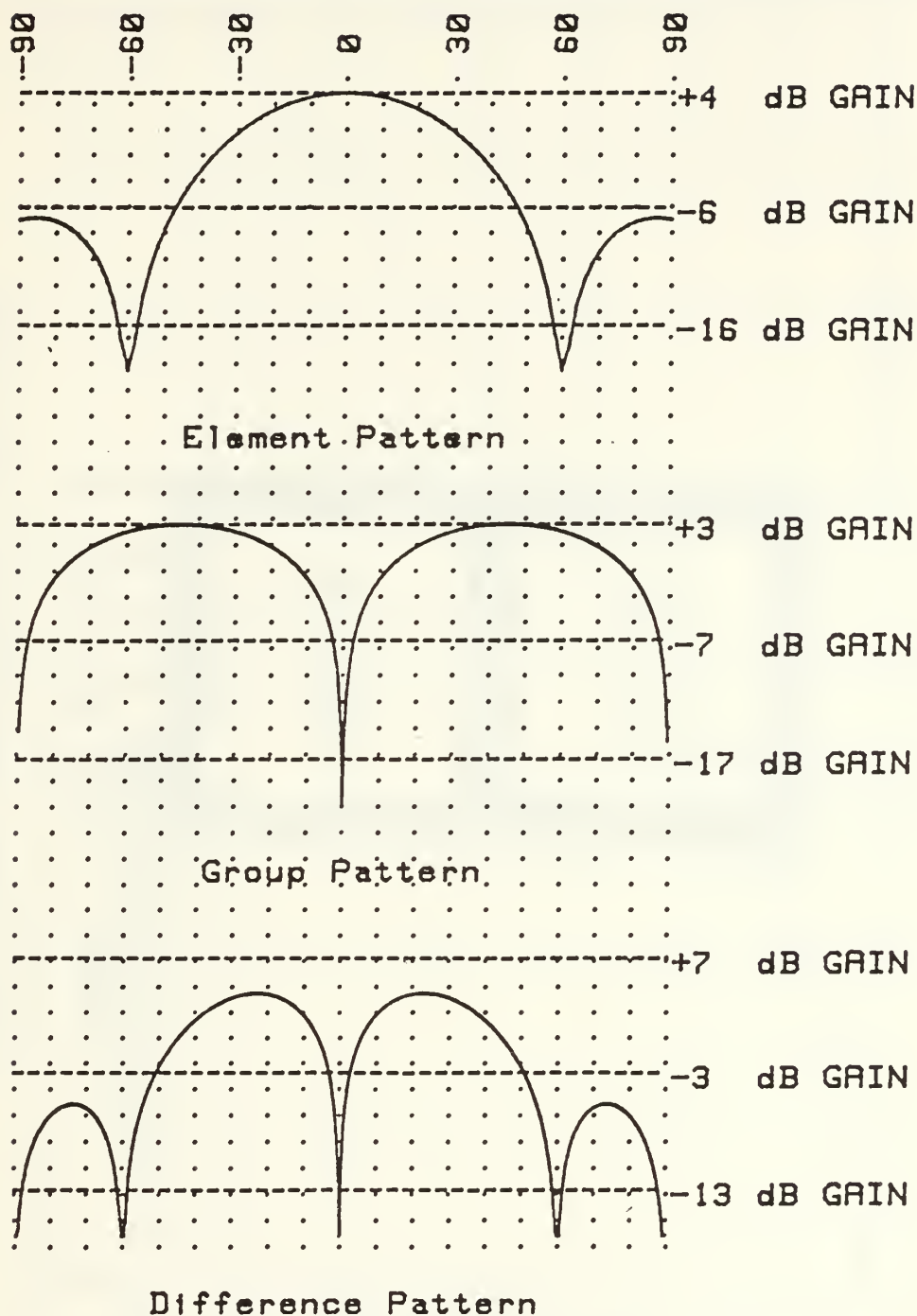


Figure 10 Theoretical Difference Pattern.

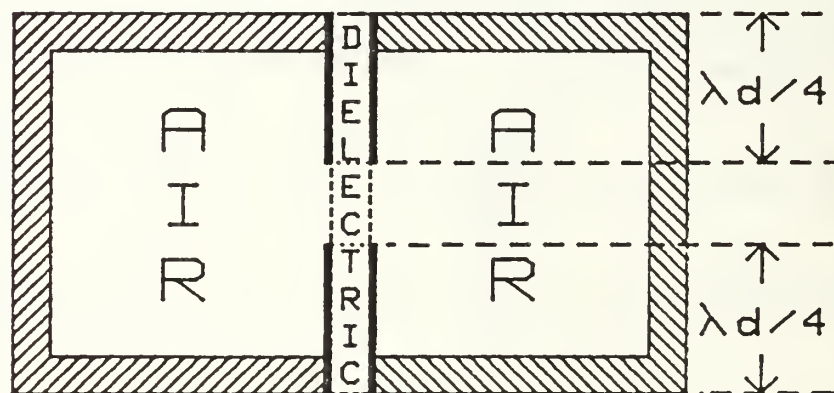


Figure 11 Bilateral Fin-Line.

SLOT LINE IMPEDANCE (ER=10.0)

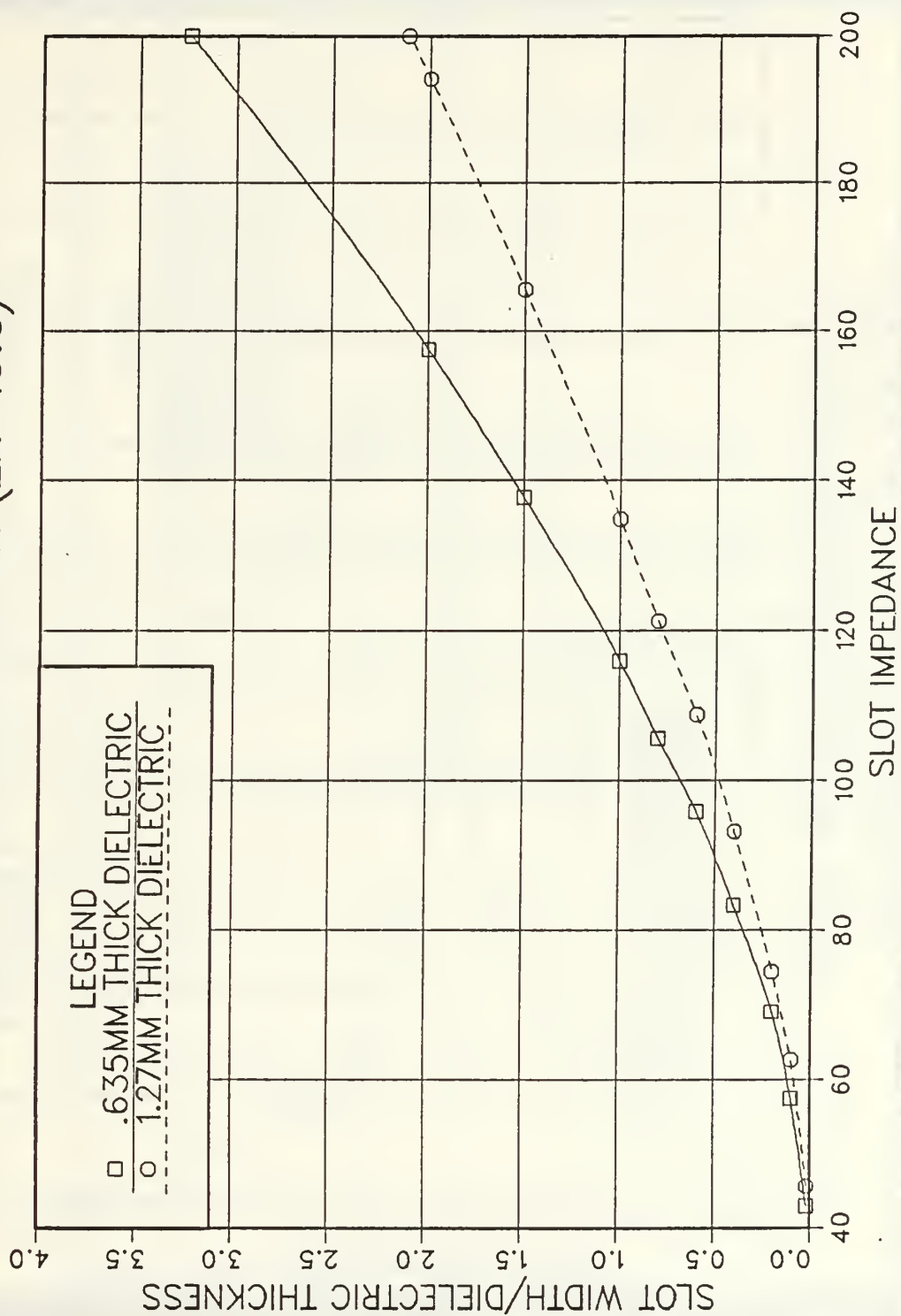


Figure 12 Slotline Impedance.

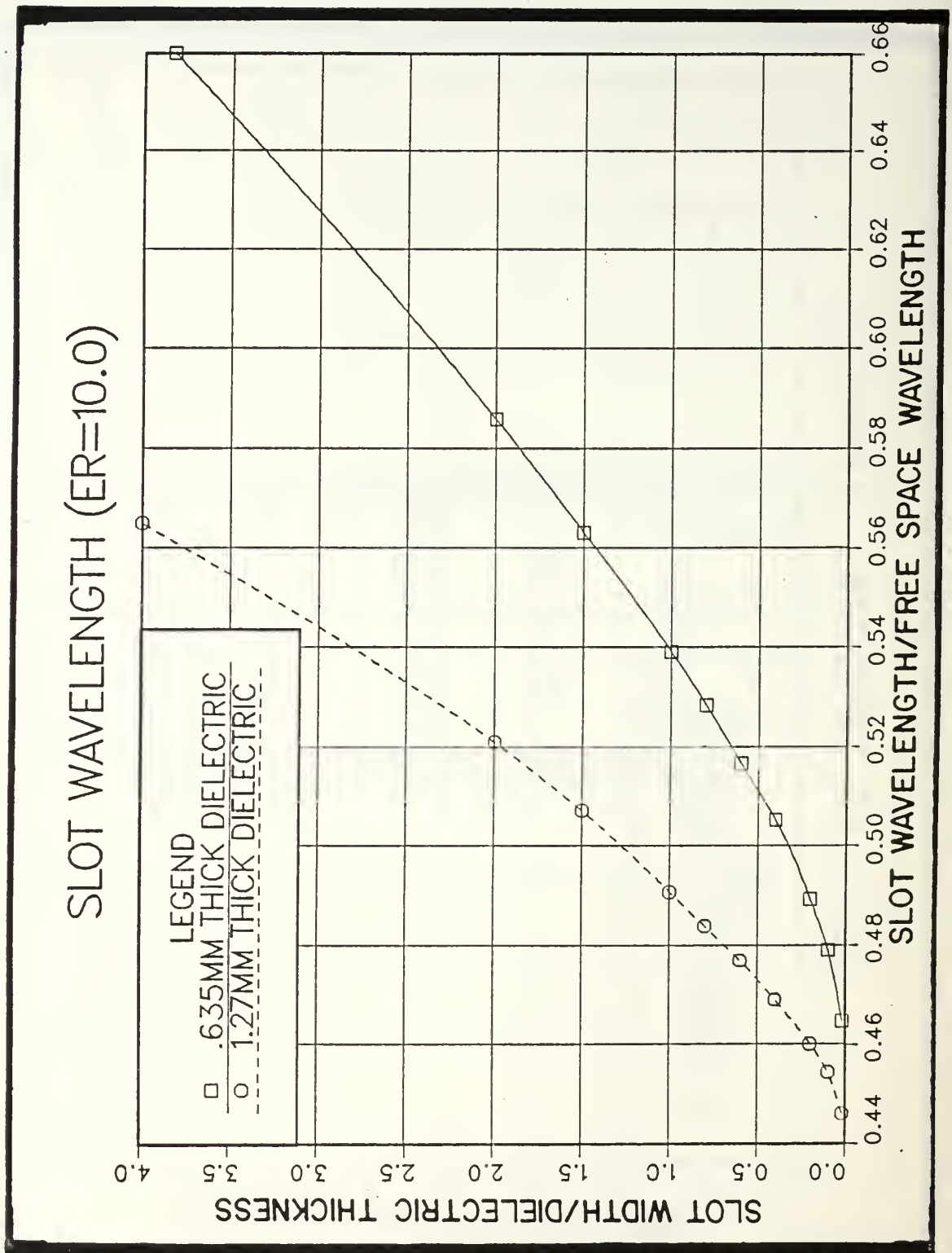


Figure 13 Slotline Wavelength.

$0 < Z_{\text{EVEN}} < 1 < Z_{\text{ODD}} < 2$

COUPLED SLOT IMPEDANCE (NORM)

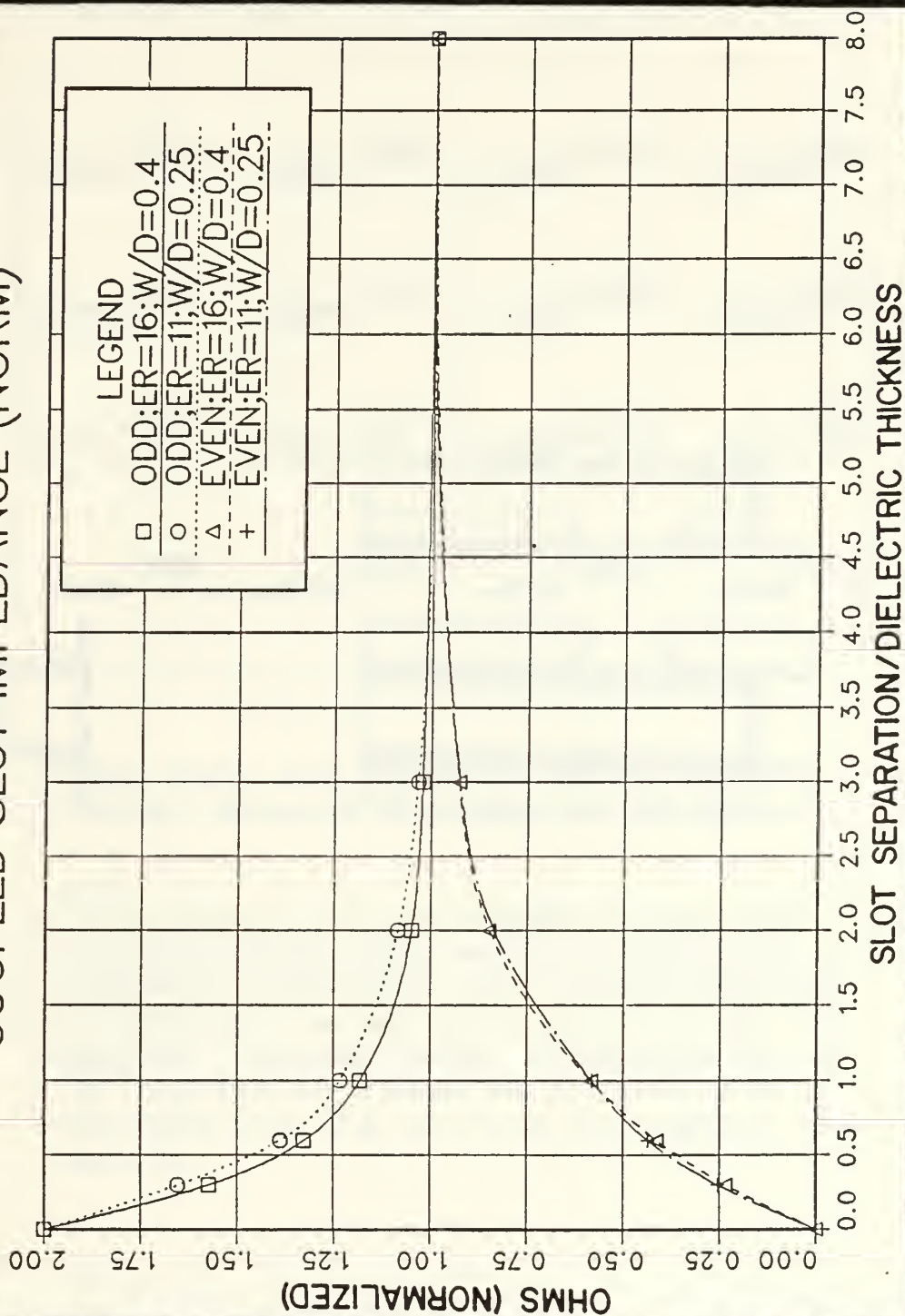


Figure 14 Normalized Coupled Slotline Impedance.

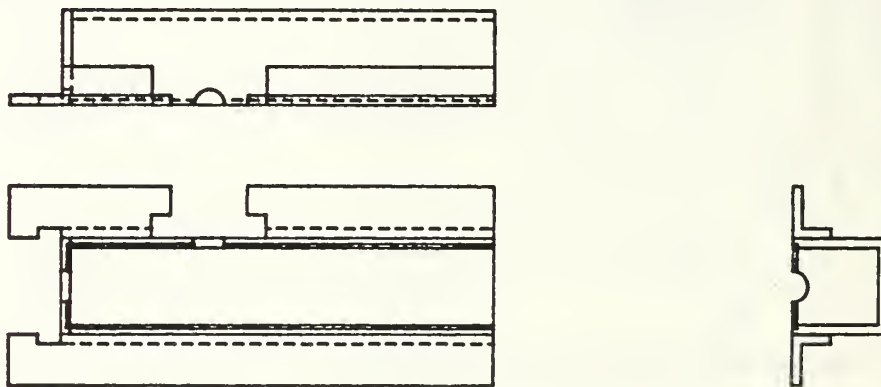


Figure 15 Original Fixture Design.

$$S = \begin{bmatrix} .202e^{-j169} & .023e^{-j023} & .462e^{+j004} & .310e^{+j006} \\ .030e^{-j030} & .269e^{-j140} & .314e^{-j170} & .192e^{-j020} \\ .407e^{-j000} & .313e^{-j179} & .132e^{-j001} & .077e^{-j069} \\ .316e^{-j002} & .277e^{+j017} & .052e^{-j042} & .154e^{+j162} \end{bmatrix}$$

This data was taken on an HP 8409B
Vector Network Analyzer at 10 GHZ.

This matrix is corrected for uneven
transmission line lengths caused by
launcher placement and fixture design.
10 degrees is added to port-1, 84
degrees is subtracted from port-3 and
22 degrees is added to port-4. The
corrections are uniform throughout the
matrix.

Figure 16 S-Matrix for Magic-Tee Number Two.

$$S = \begin{bmatrix} .452e^{-j157} & .042e^{+j046} & .473e^{+j005} & .327e^{+j004} \\ .100e^{+j042} & .483e^{-j169} & .292e^{-j173} & .410e^{-j009} \\ .442e^{-j008} & .280e^{-j182} & .435e^{+j024} & .046e^{+j012} \\ .305e^{-j007} & .376e^{+j003} & .048e^{+j011} & .170e^{+j008} \end{bmatrix}$$

This data was taken on an HP 8409B
Vector Network Analyzer at 11.4 GHZ.

This matrix is corrected for uneven
transmission line lengths caused by
launcher placement and fixture design.
106 degrees is added to port-1, 122
degrees is added to port-2 and 180
degrees is added to port-3. The
corrections are uniform throughout the
matrix.

Figure 17 S-Matrix for Magic-Tee Number Three.

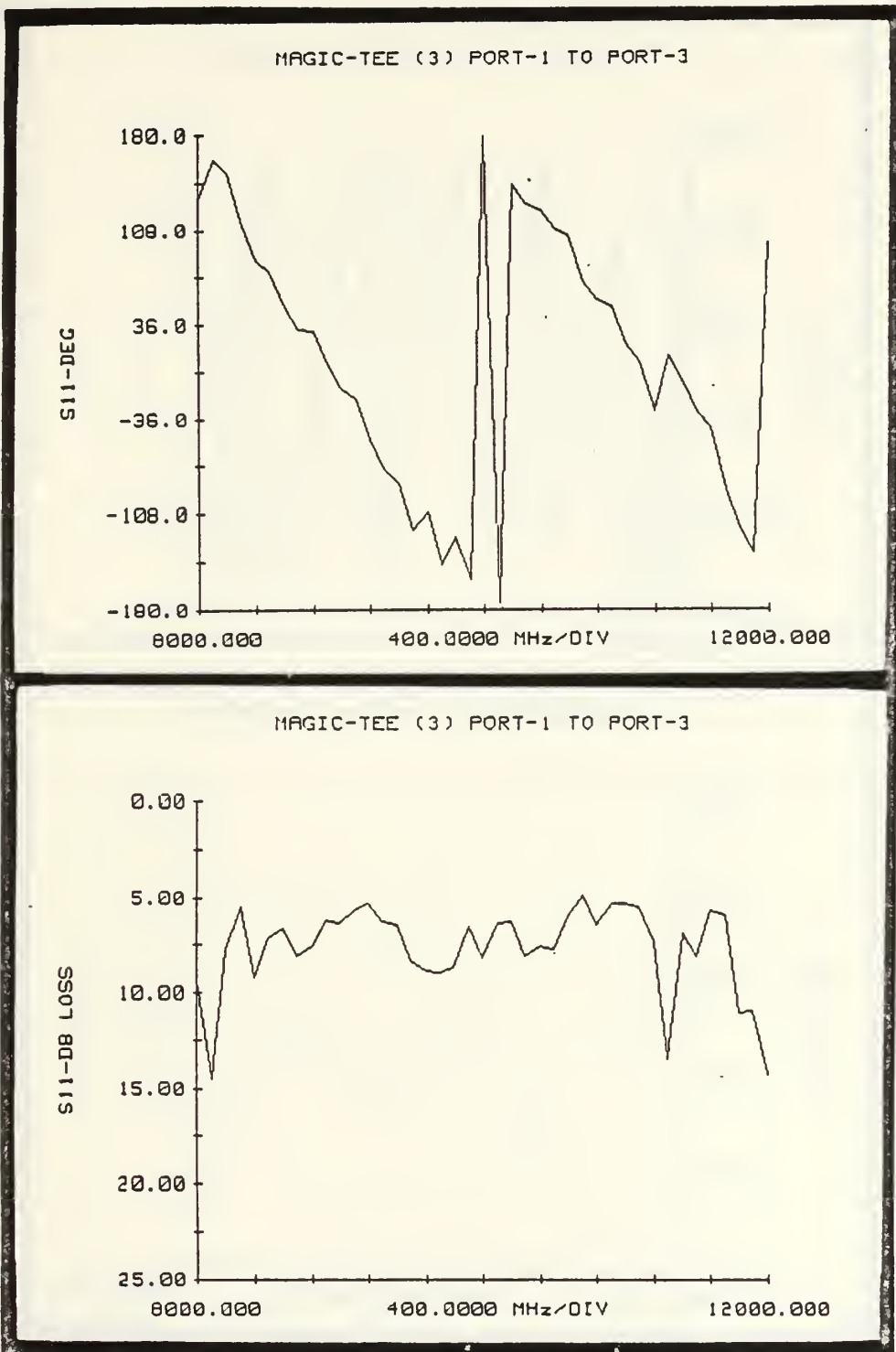


Figure 18 S11 Phase and Magnitude for Magic-Tee Three.

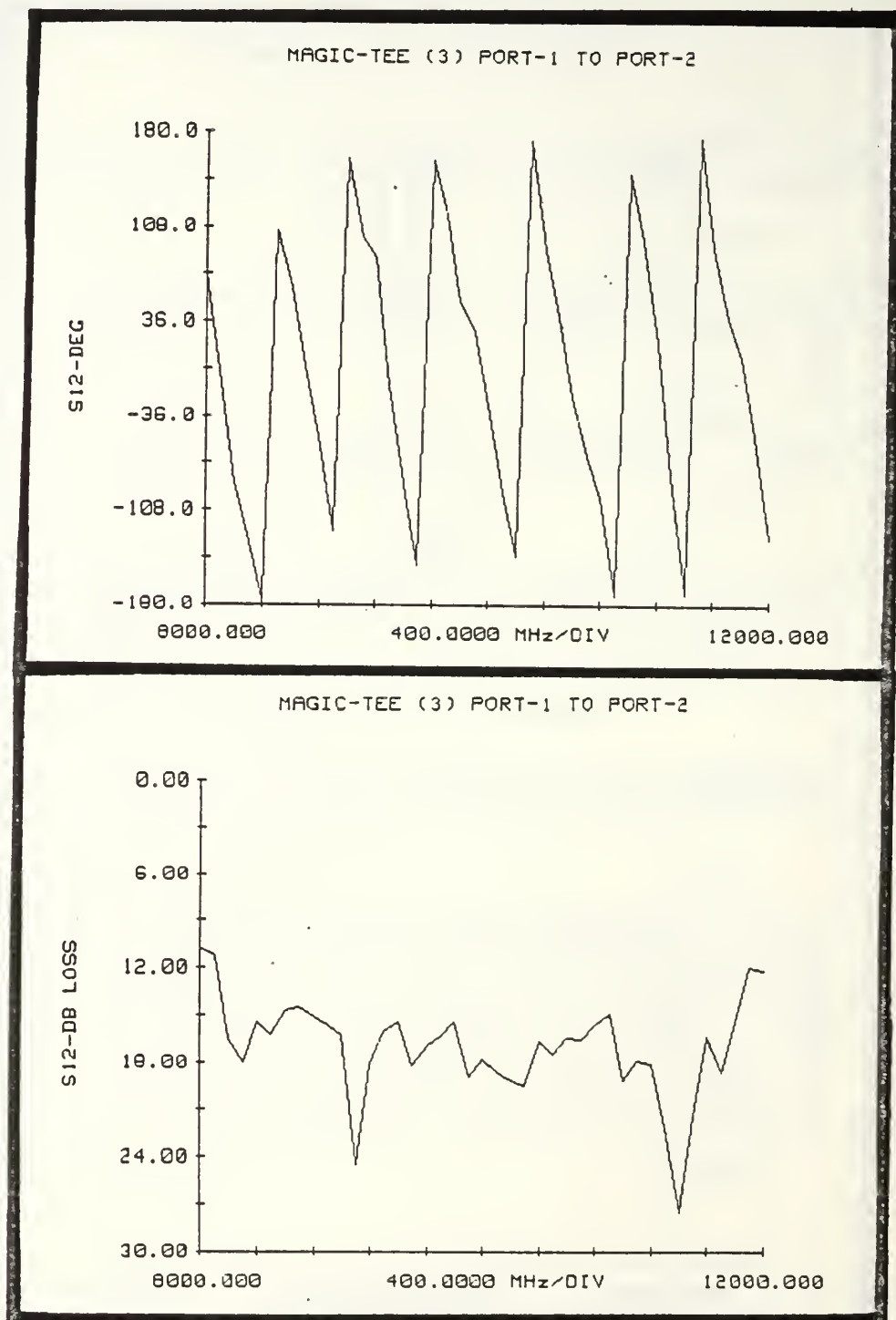


Figure 19 S12 Phase and Magnitude for Magic-Tee Three.

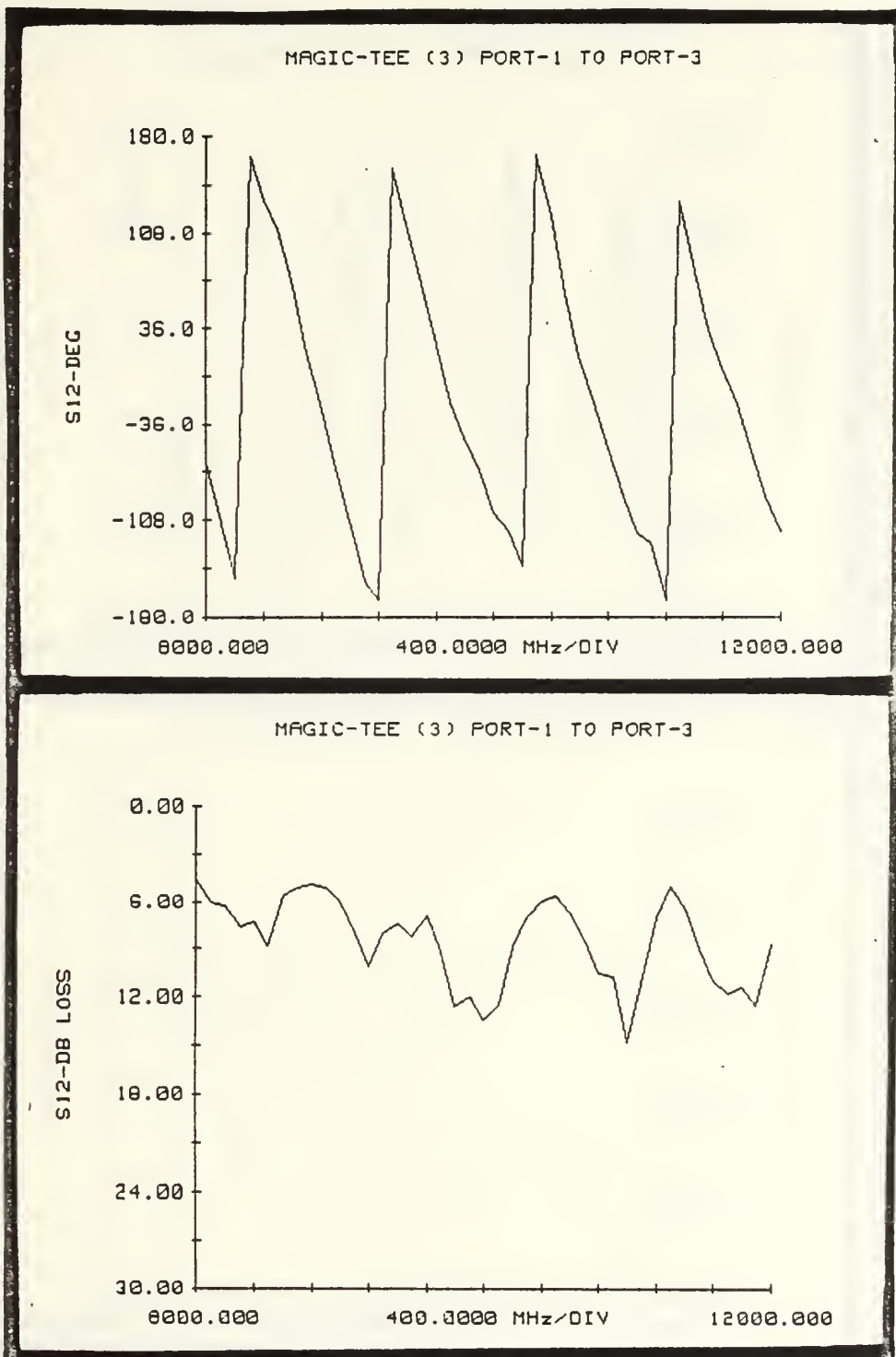


Figure 20 S13 Phase and Magnitude for Magic-Tee Three.

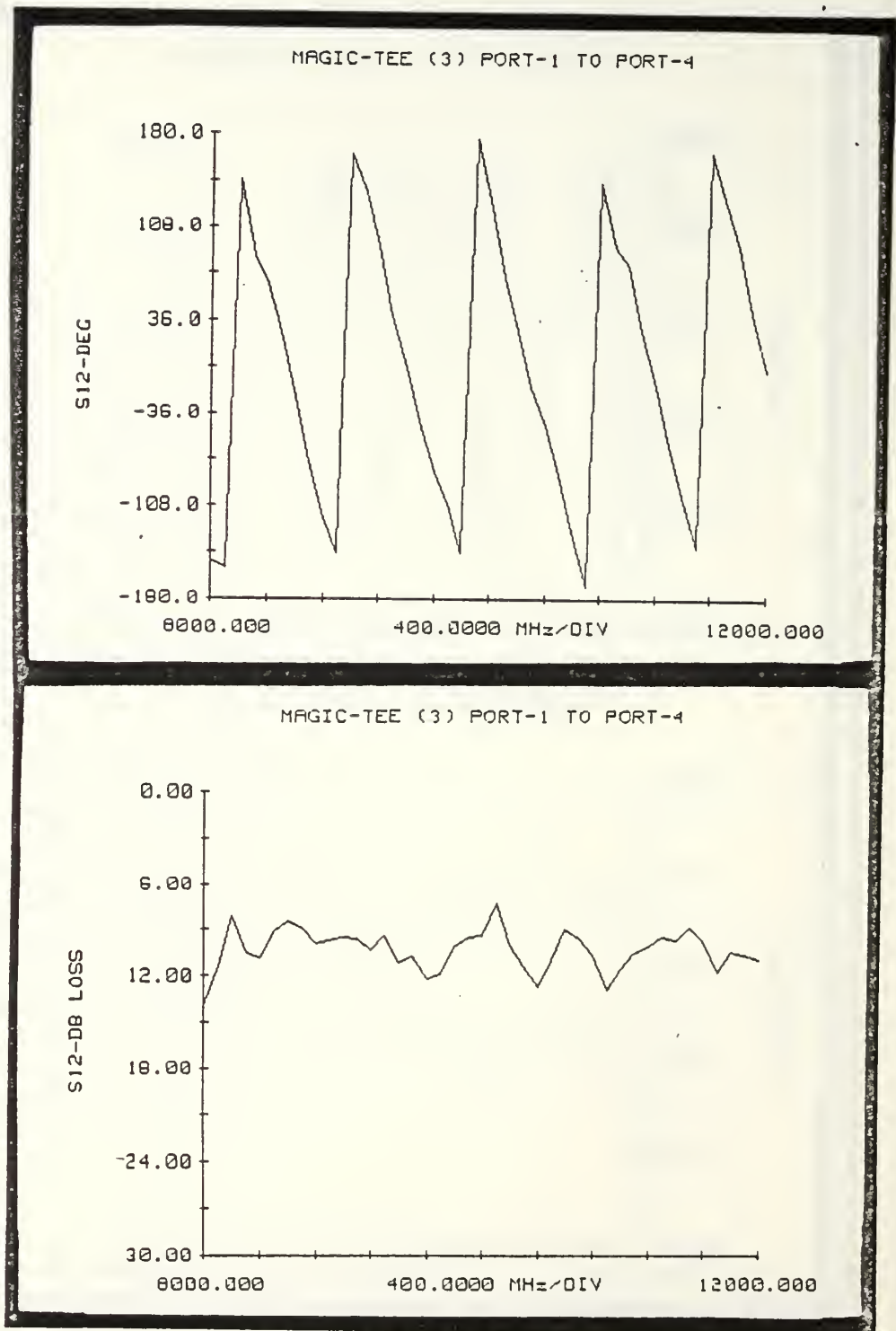


Figure 21 S14 Phase and Magnitude for Magic-Tee Three.

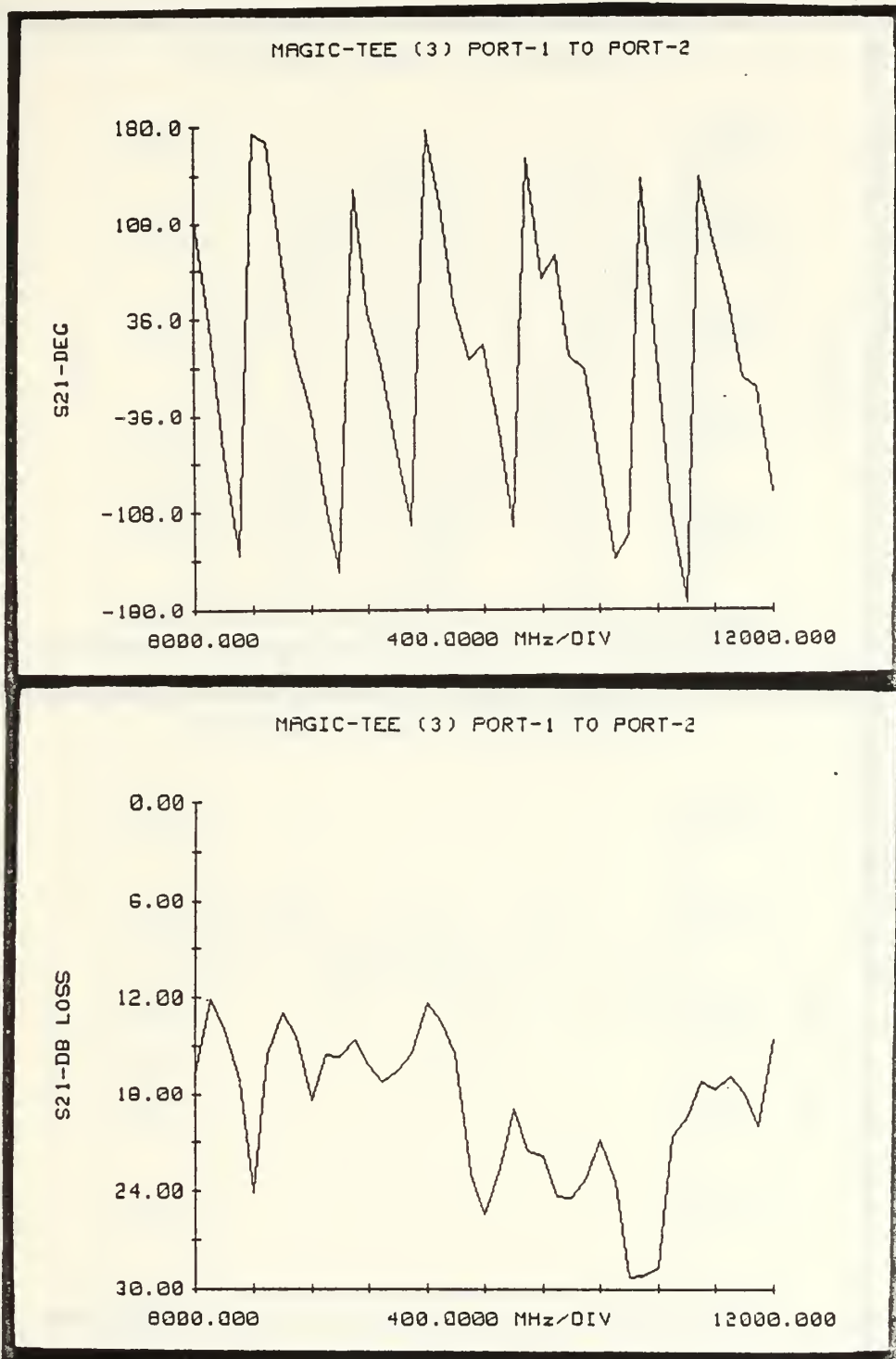


Figure 22 S21 Phase and Magnitude for Magic-Tee Three.

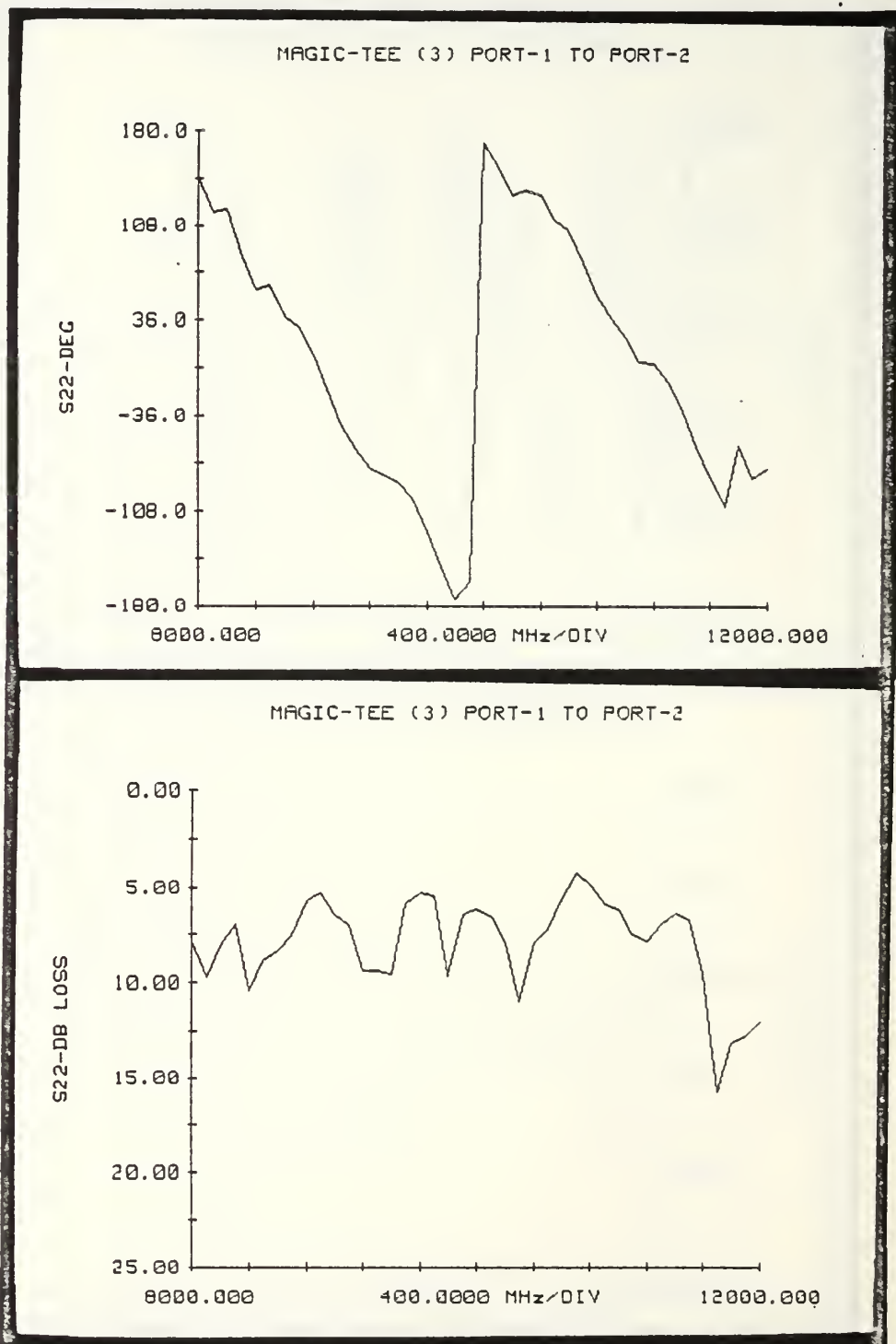


Figure 23 S22 Phase and Magnitude for Magic-Tee Three.

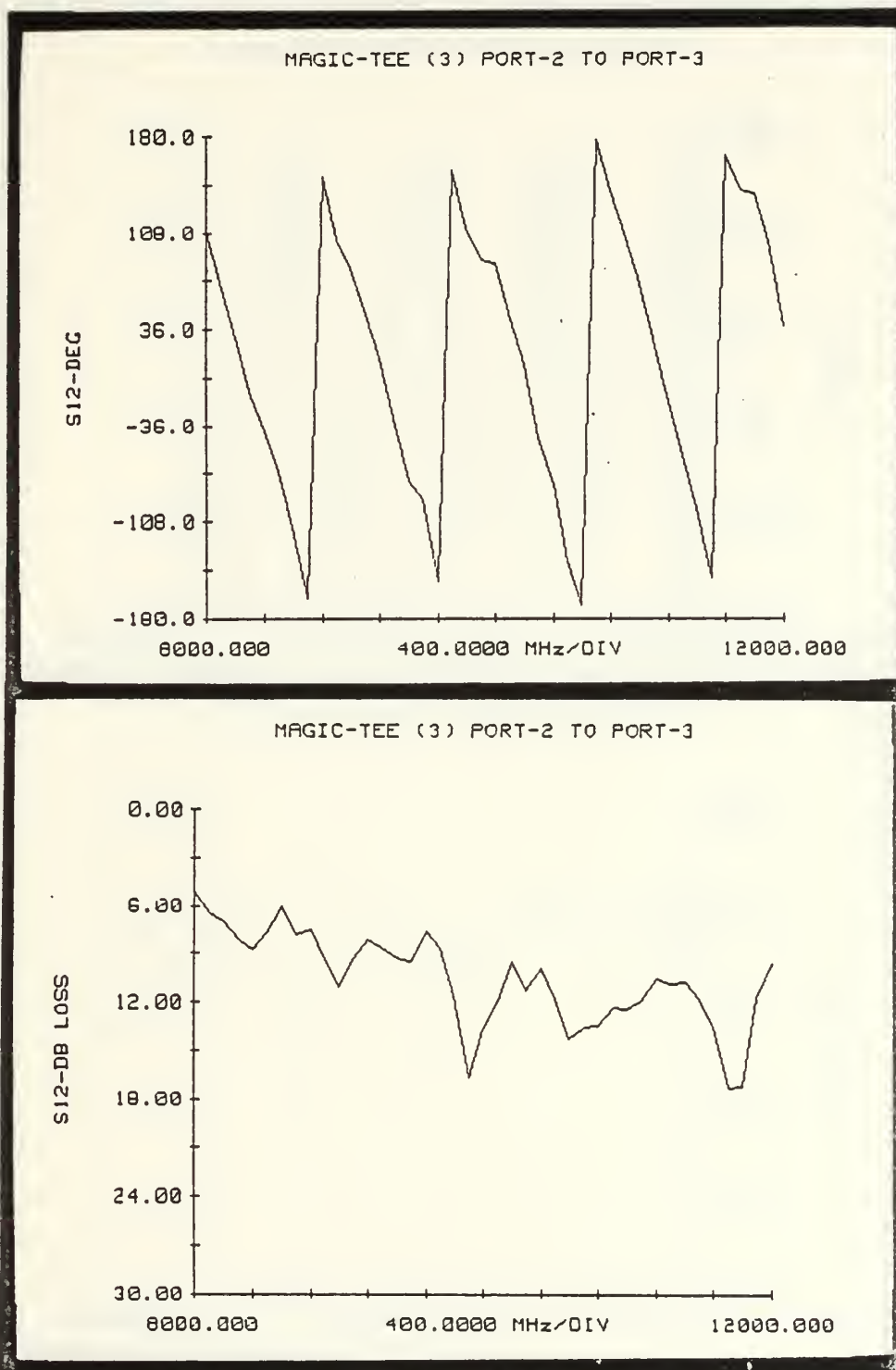


Figure 24 S23 Phase and Magnitude for Magic-Tee Three.

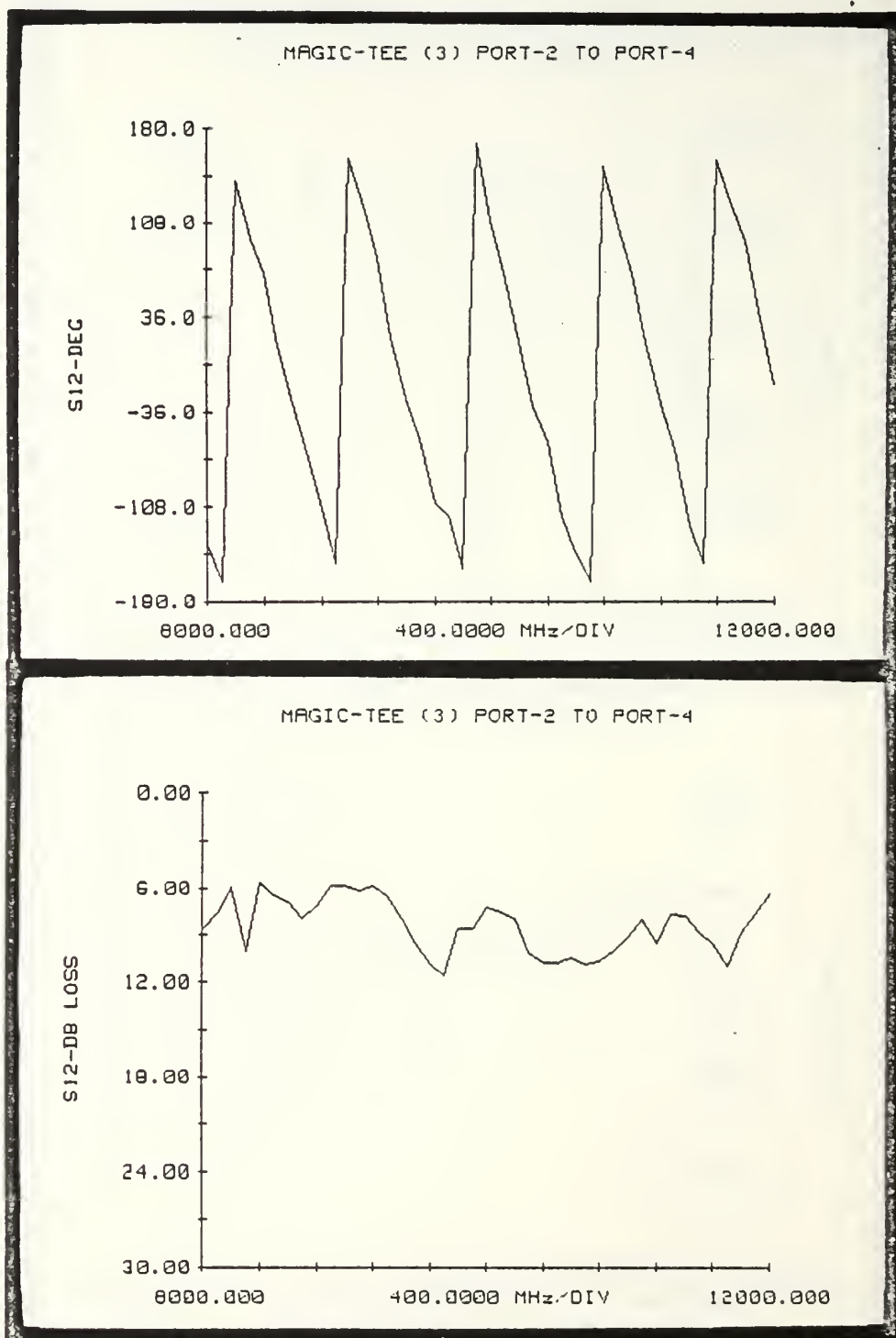


Figure 25 S24 Phase and Magnitude for Magic-Tee Three.

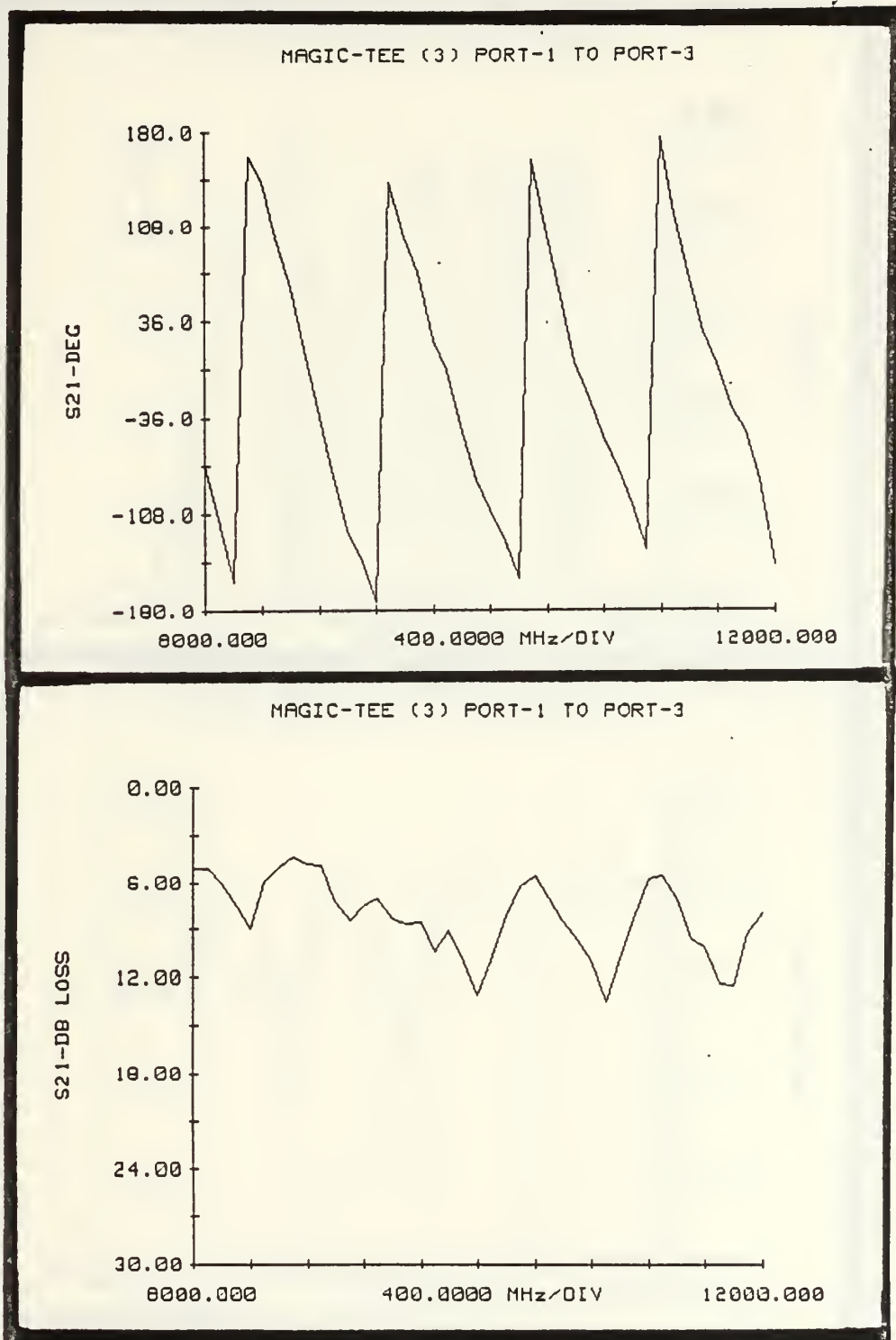


Figure 26 S31 Phase and Magnitude for Magic-Tee Three.

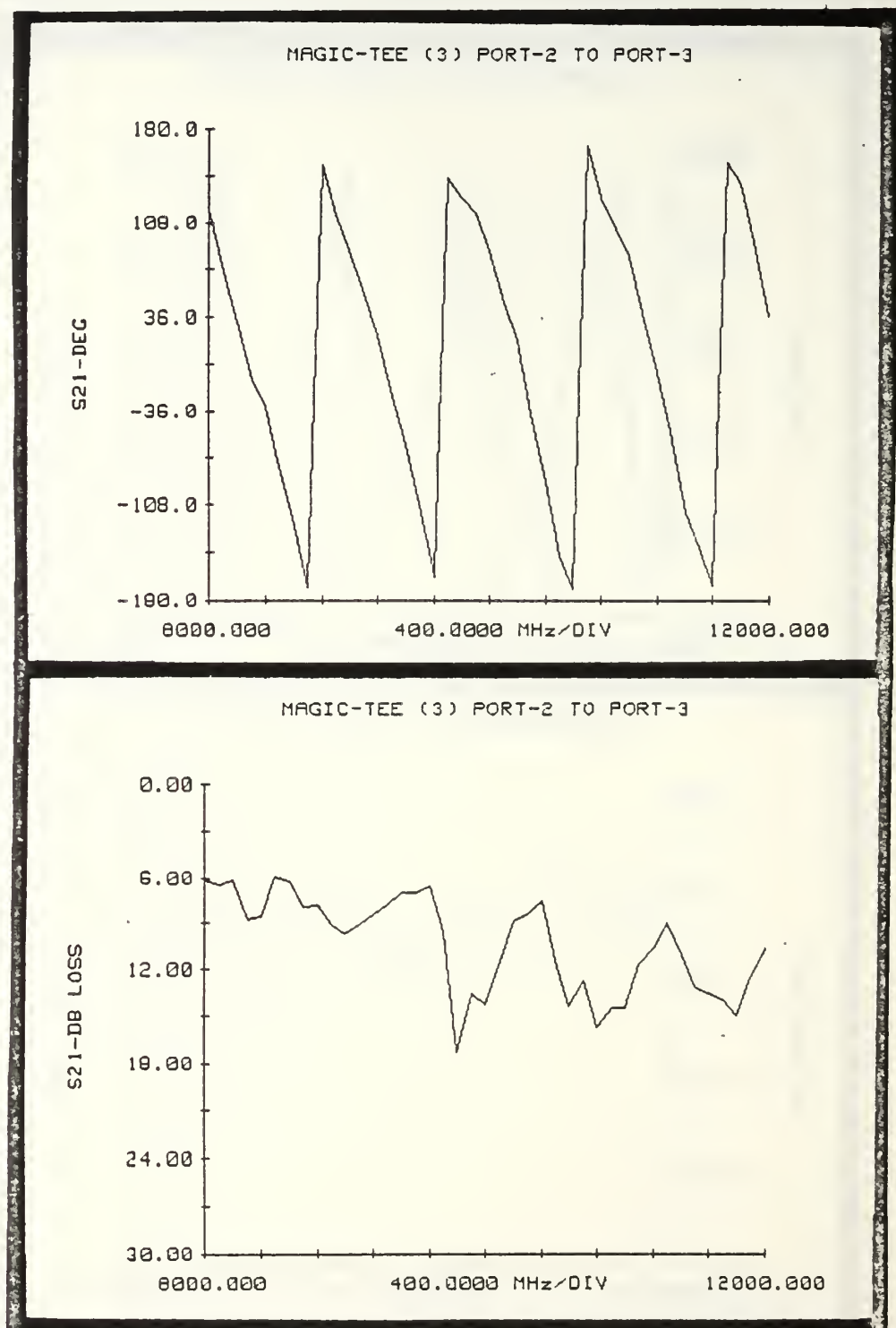


Figure 27 S32 Phase and Magnitude for Magic-Tee Three.

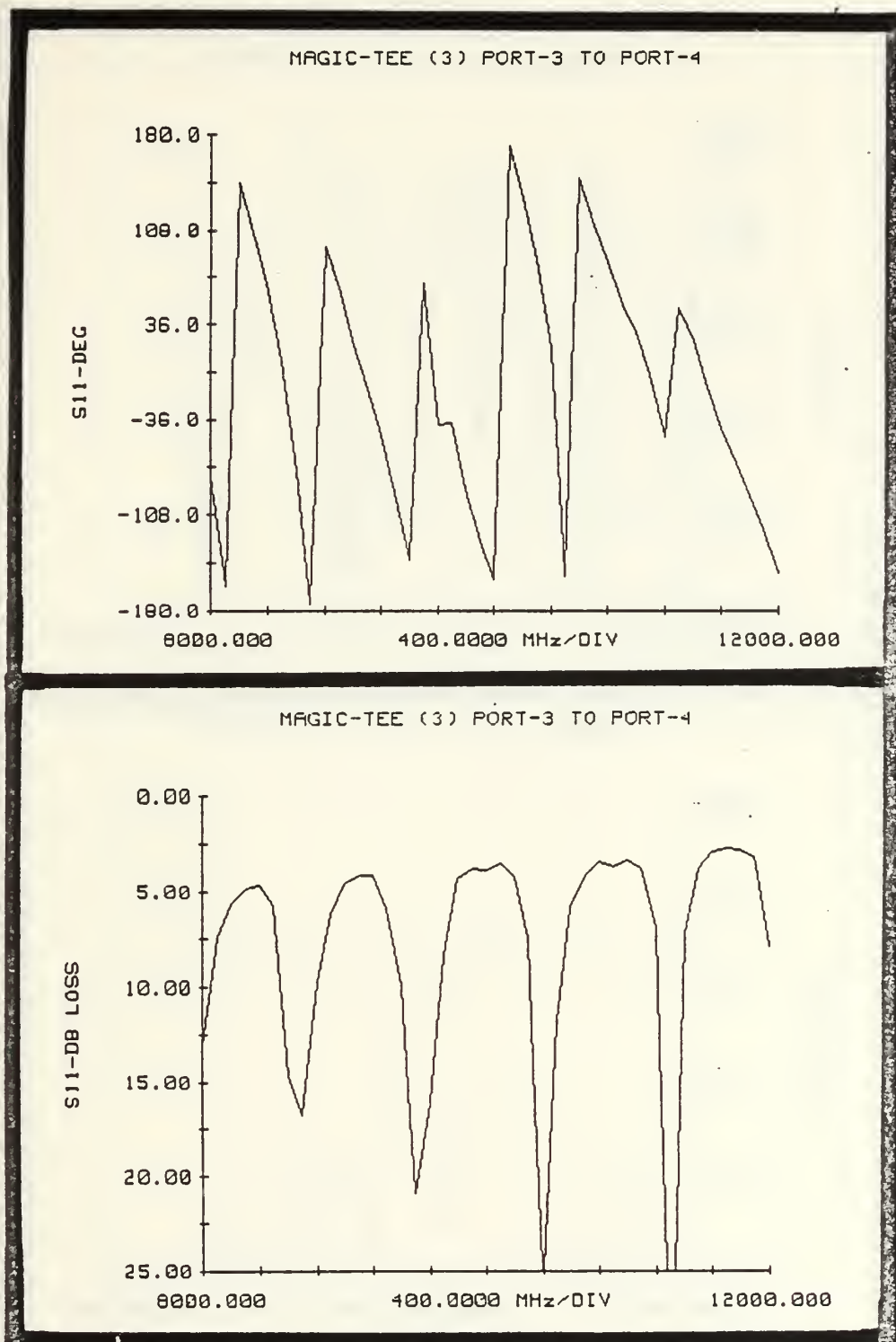


Figure 28 S33 Phase and Magnitude for Magic-Tee Three.

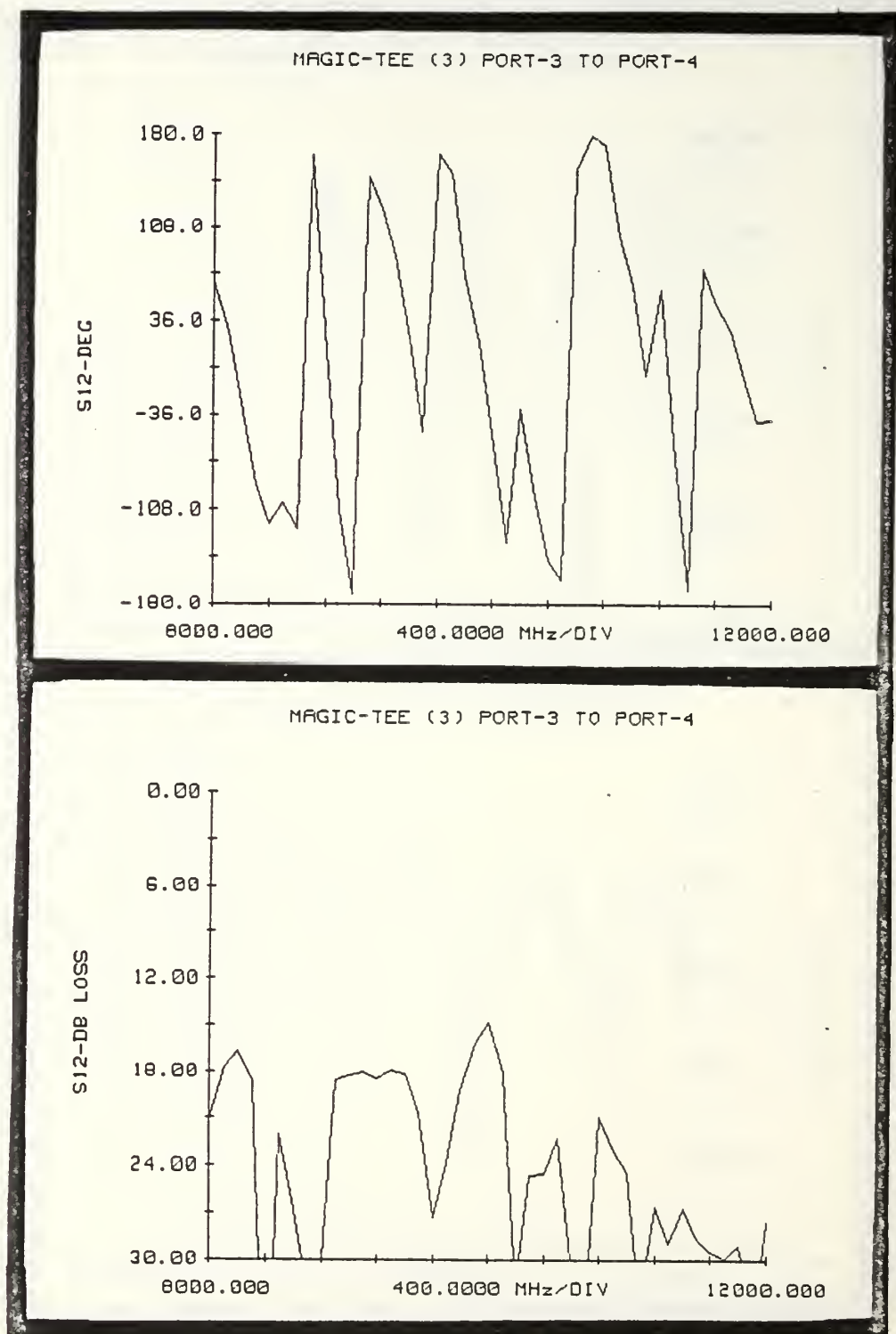


Figure 29 S34 Phase and Magnitude for Magic-Tee Three.

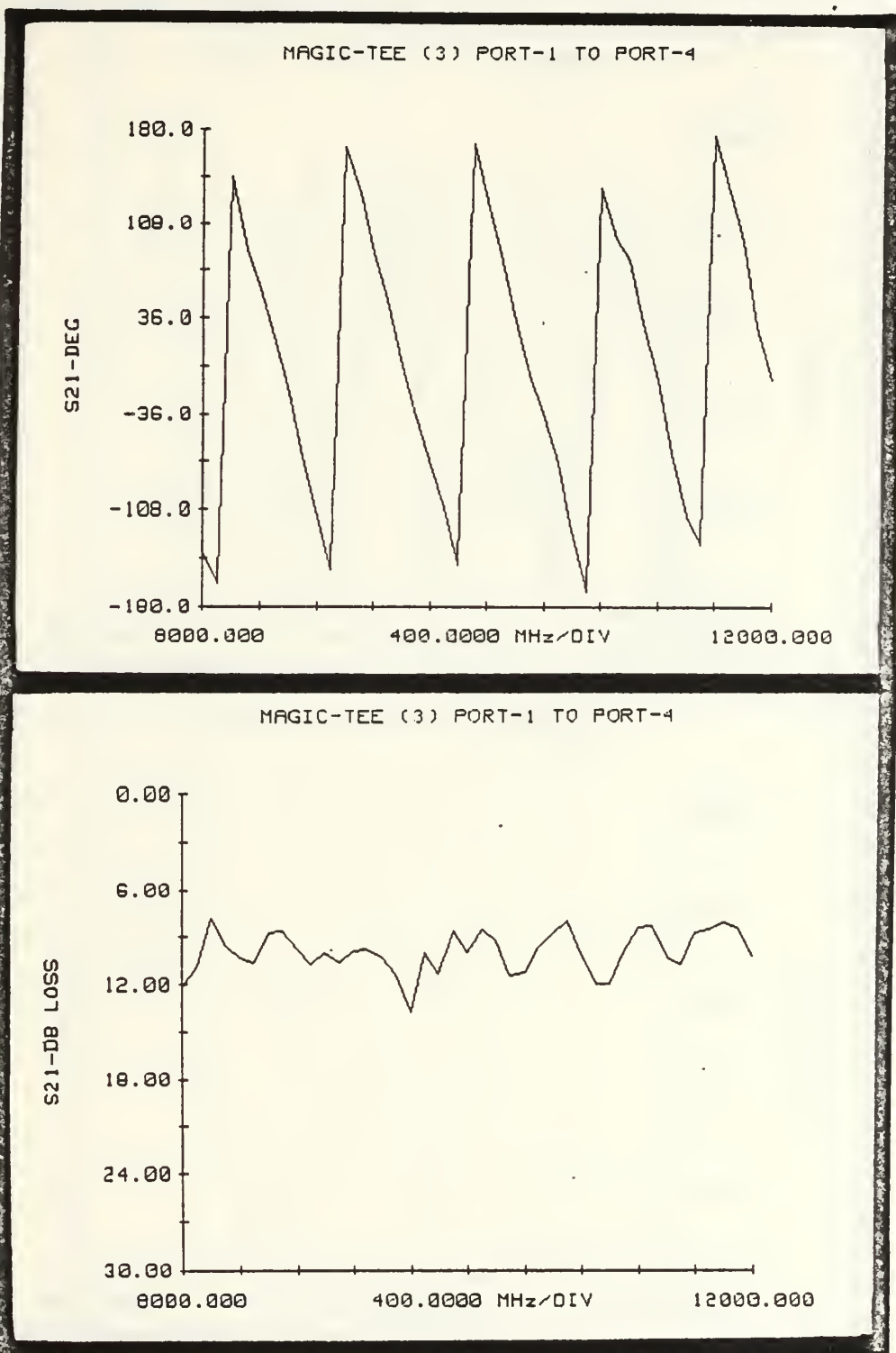


Figure 30 S41 Phase and Magnitude for Magic-Tee Three.

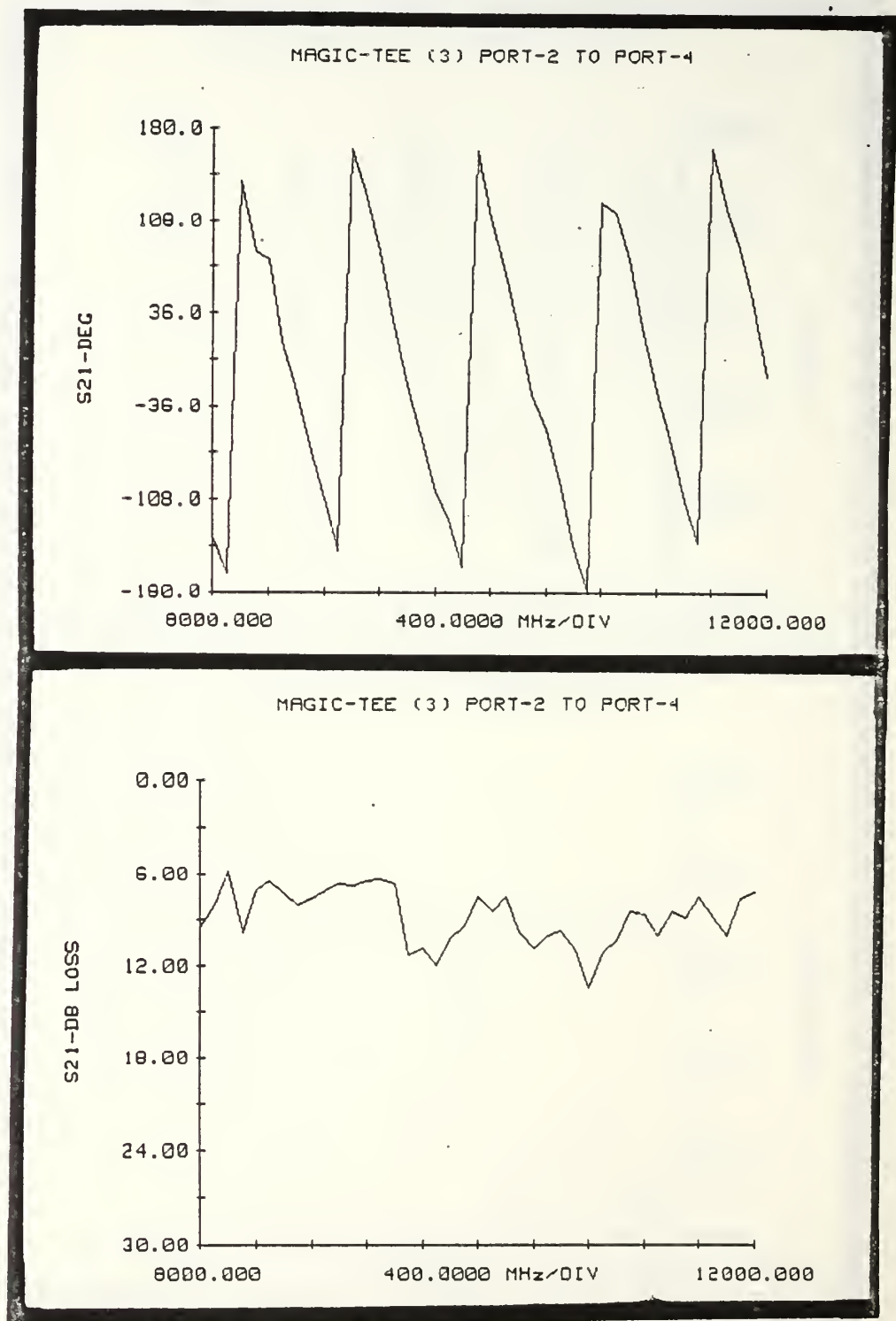


Figure 31 S42 Phase and Magnitude for Magic-Tee Three.

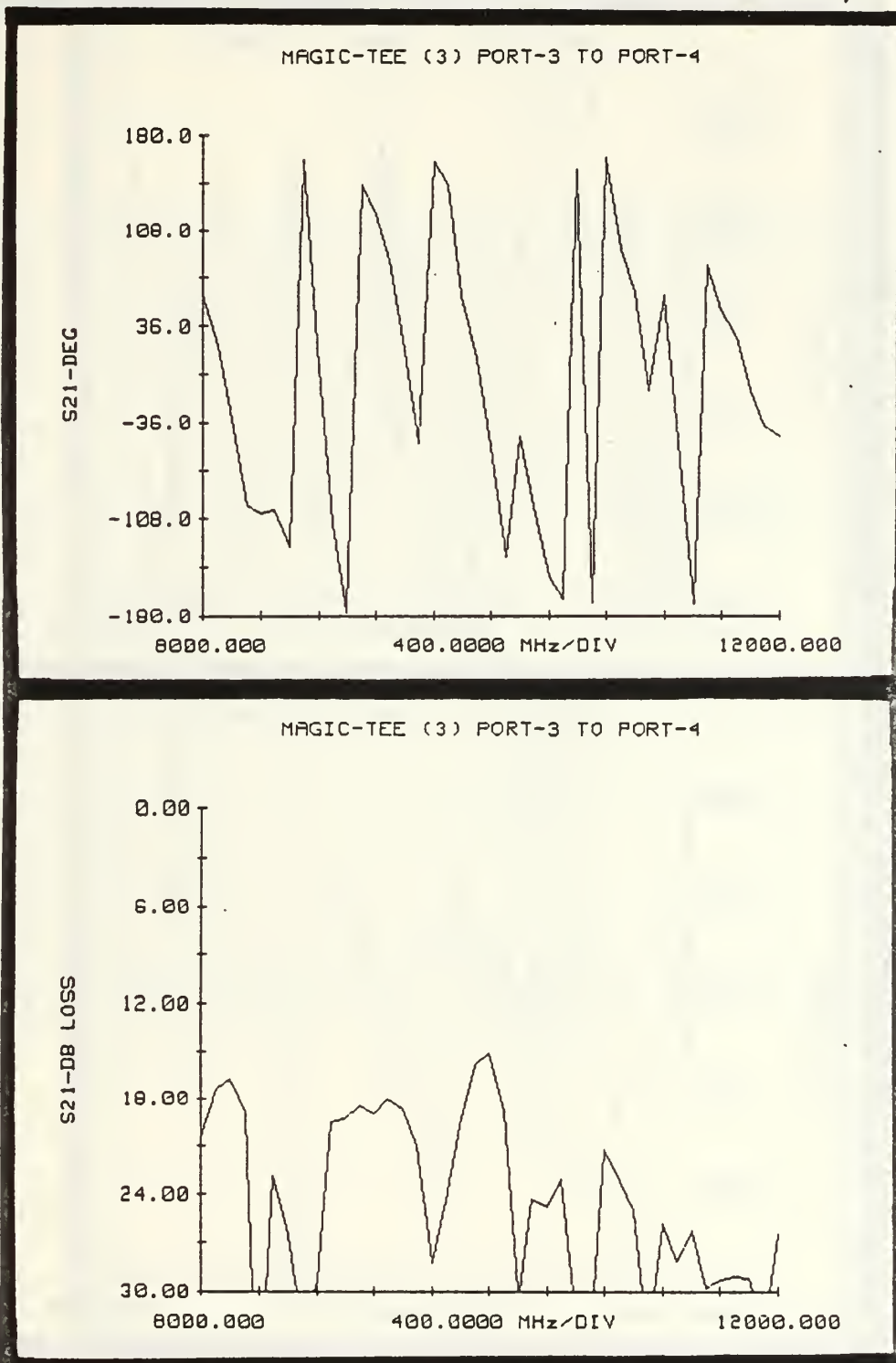


Figure 32 S43 Phase and Magnitude for Magic-Tee Three.

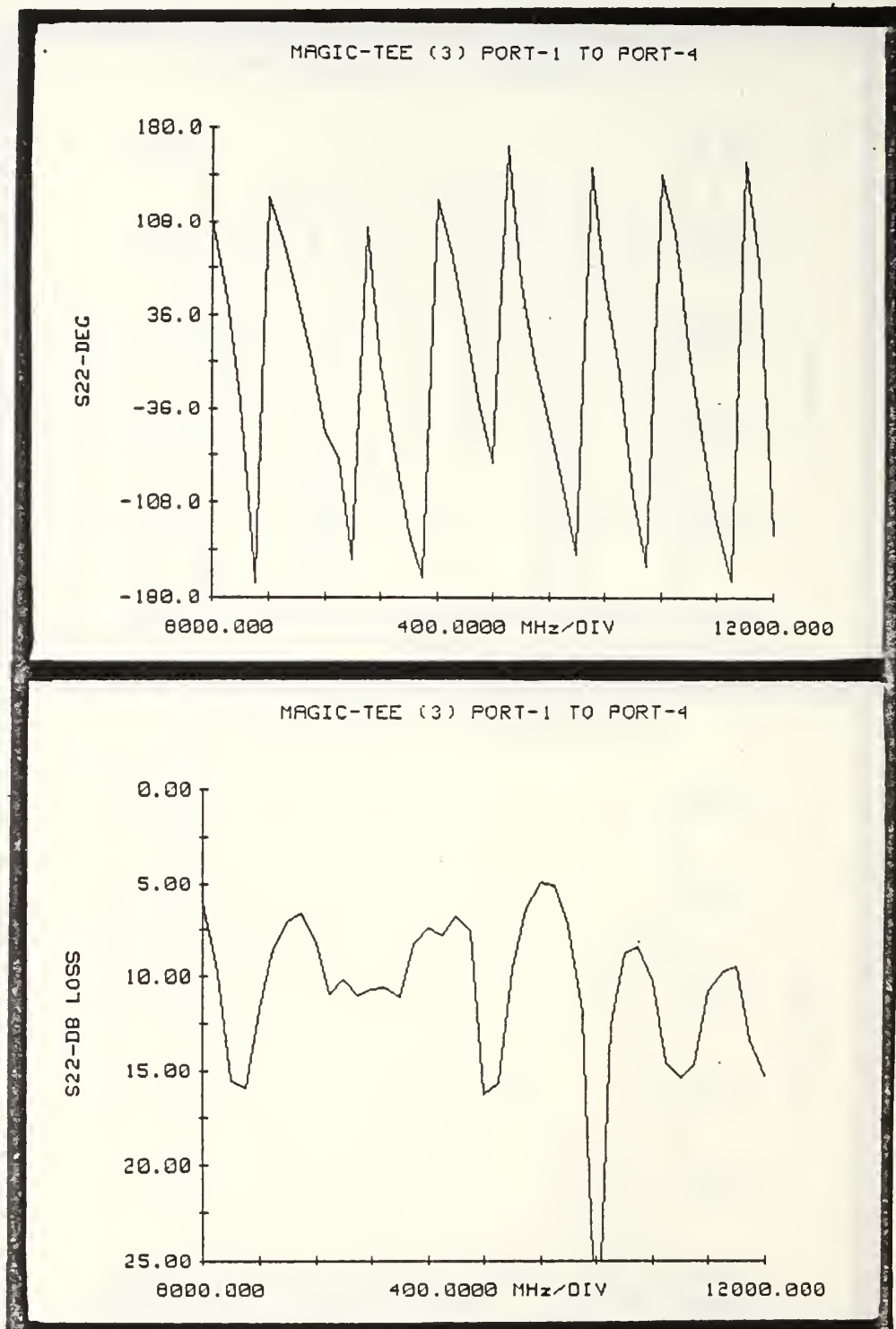


Figure 33 S44 Phase and Magnitude for Magic-Tee Three.

FINLINE MONOPULSE COMPARATOR

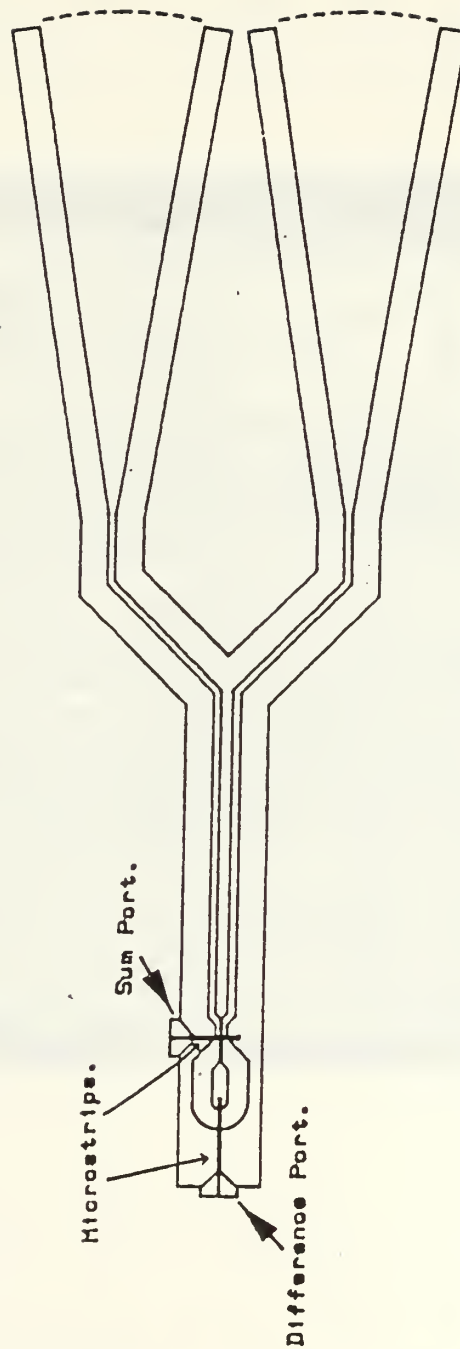


Figure 34 Fin-Line Monopulse System.

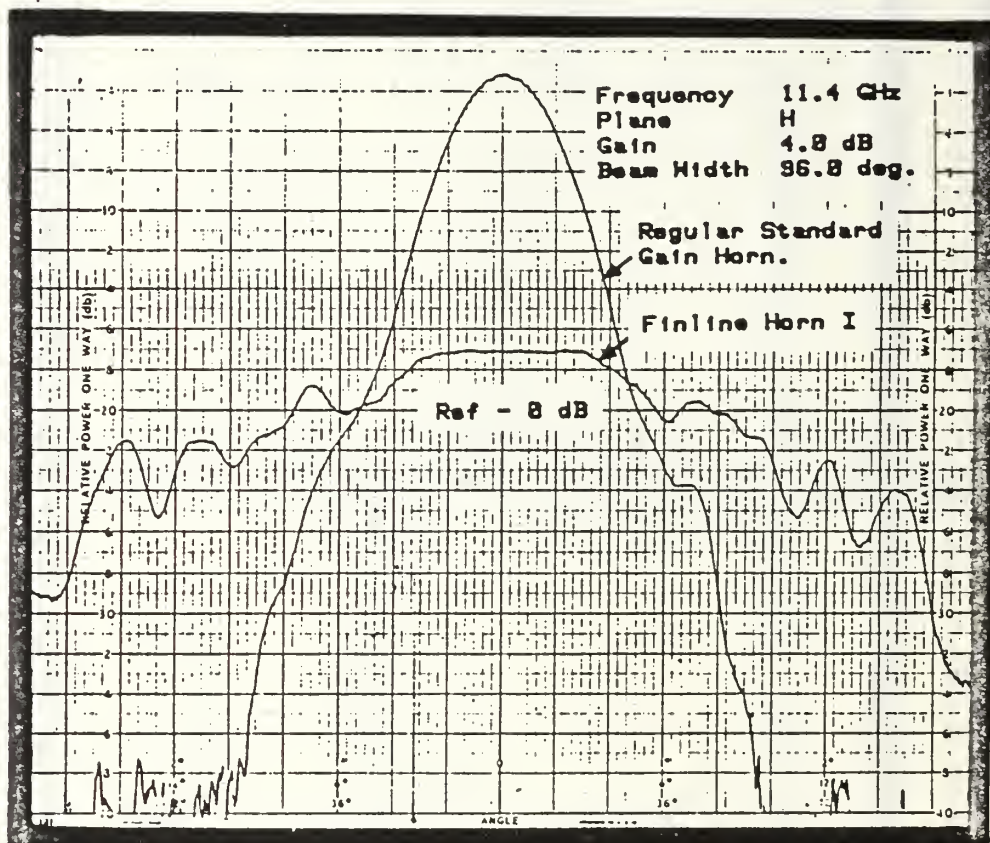


Figure 35 H-Plane Element Pattern.

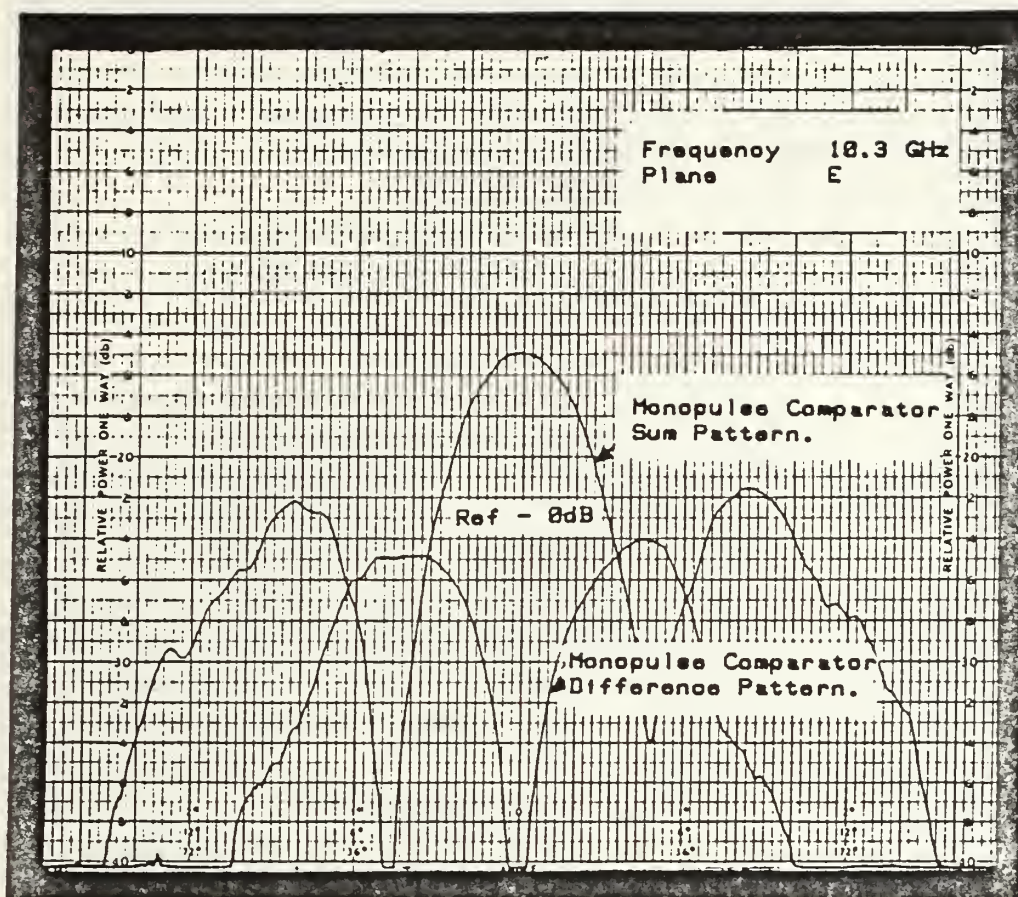


Figure 36 E-Plane System Pattern.

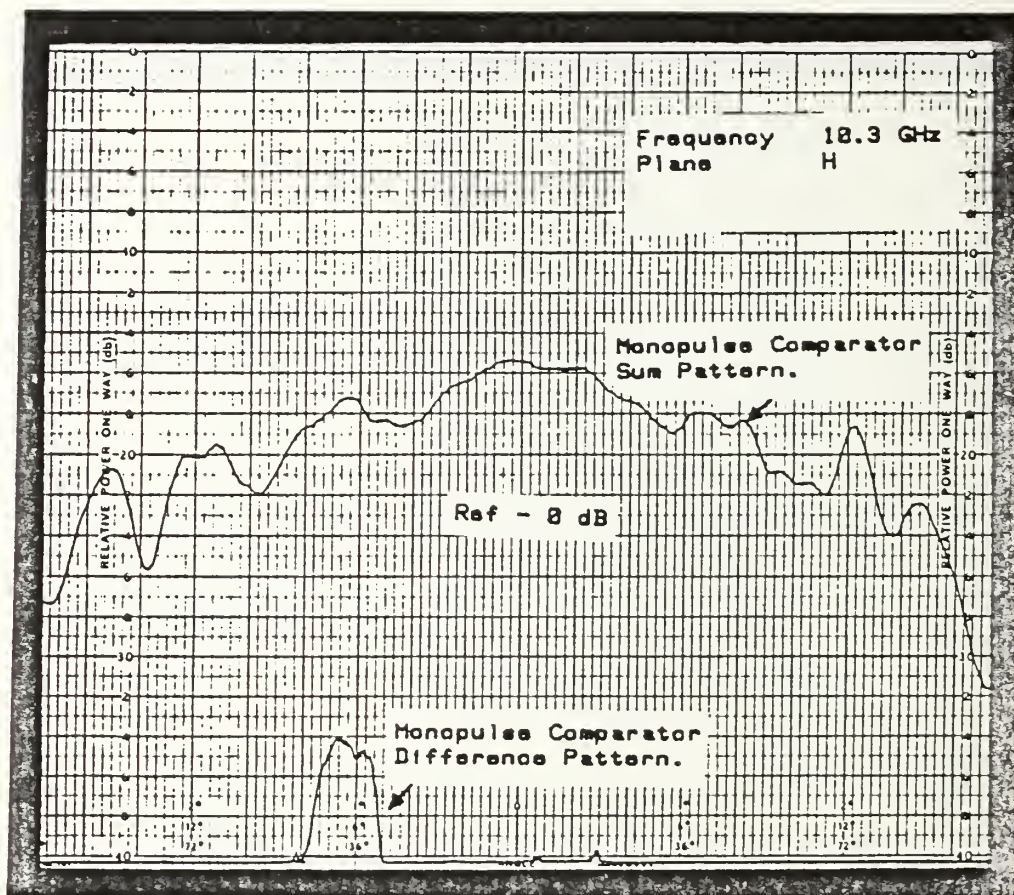


Figure 37 H-Plane System Pattern.

Degrees Left(-) and Right(+) of Boresight

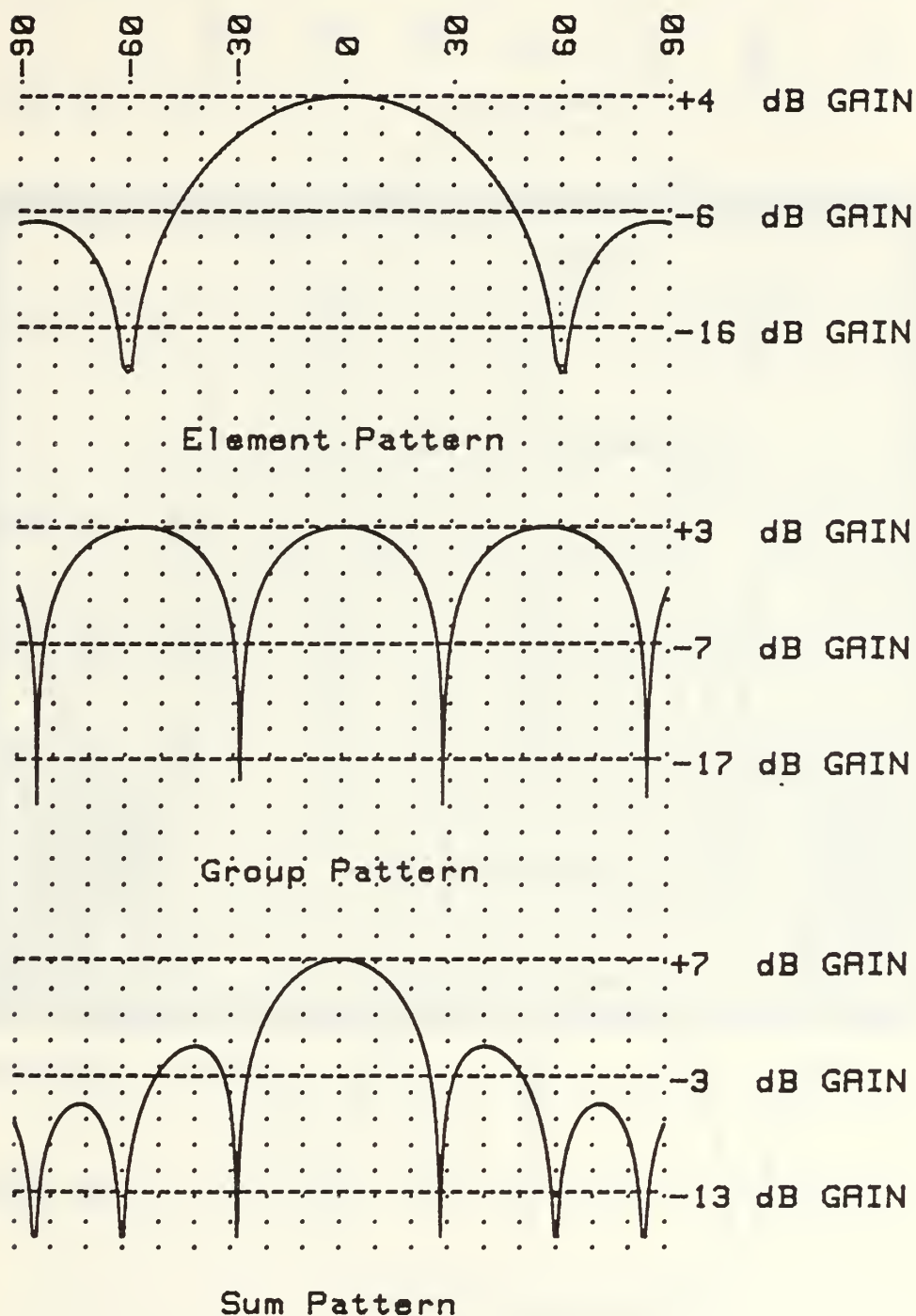


Figure 38 Simulated Sum Pattern.

Degrees Left(-) and Right(+) of Boresight

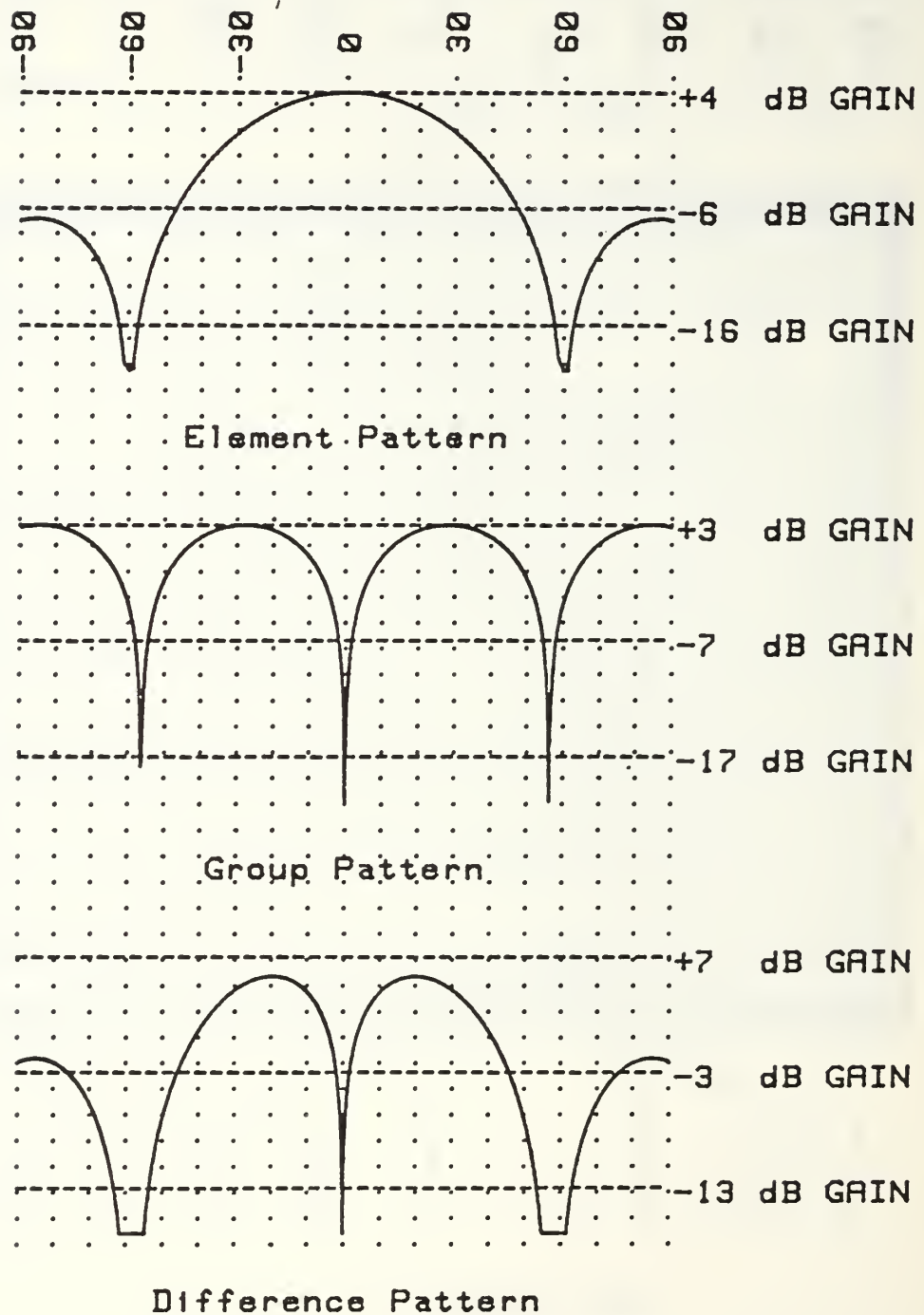


Figure 39 Simulated Difference Pattern.

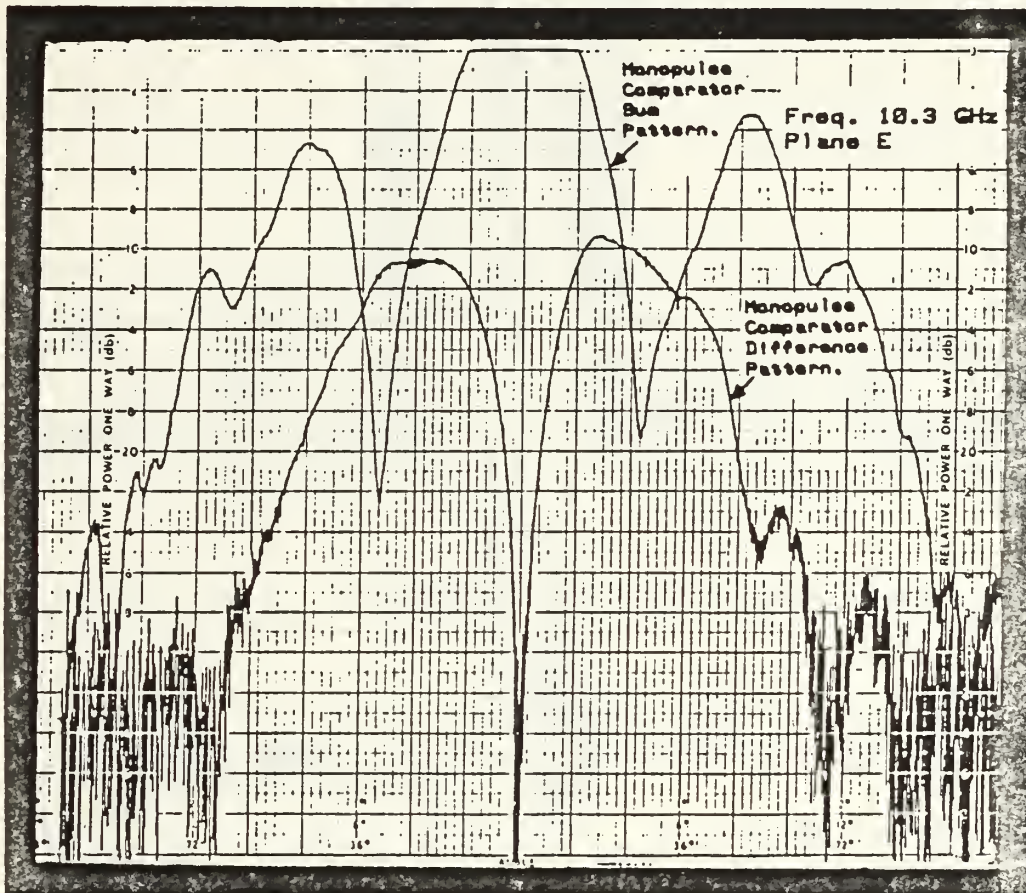


Figure 40 Depth of the Difference Null.

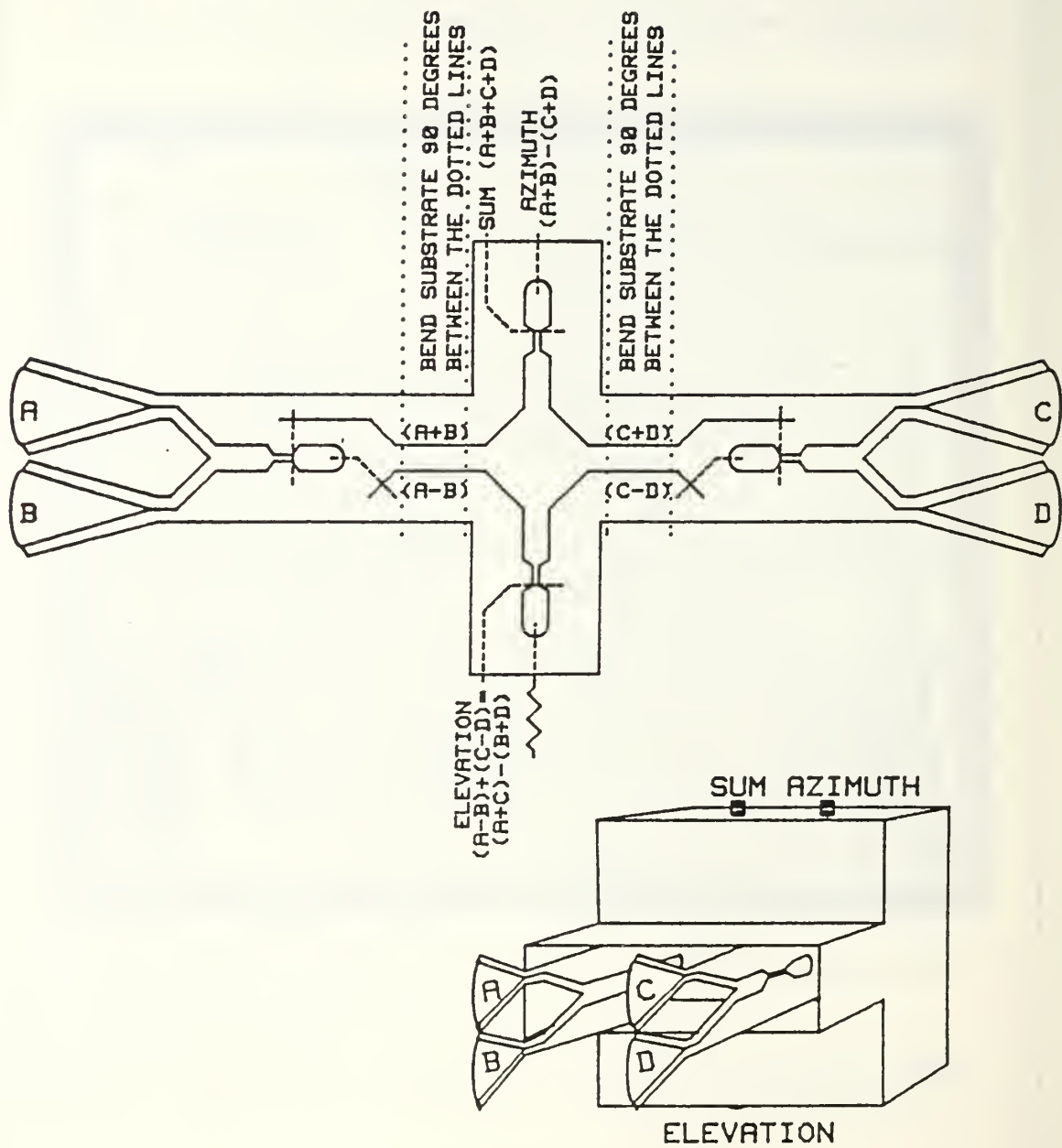


Figure 41 Dual Plane Fin-Line Monopulse System.

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1. Avionics Laboratory, Air Force Wright Aeronautical Laboratories Report PB84-108711, Microwave Receivers and Related Components, by J.E. Tsui, 1983.
2. Kefalas, G. P., and Wiltse, J. C., Chap. 8, "Transmission Lines, Components, and Devices," Skolnik, M. I. (Editor-in-Chief), Radar Handbook, McGraw-Hill Book Co., 1970.
3. Syrigos, H., Crossland, D., and Van Wyck, B., "Planar Waveguide Yields MM-Wave Monopulse Comparators," Reprinted from Microwaves & RF, March 1984.
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